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**DSTL ltr dtd 15 Feb 2007; DSTL ltr dtd 15 Feb 2007**

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OF THE  
ROYAL NAVAL  
SCIENTIFIC SERVICE



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Vol 20

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MAY 1965

★

No. 3

RESTRICTED

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# Journal of the Royal Naval Scientific Service

Vol. 20

MAY, 1965

No. 3

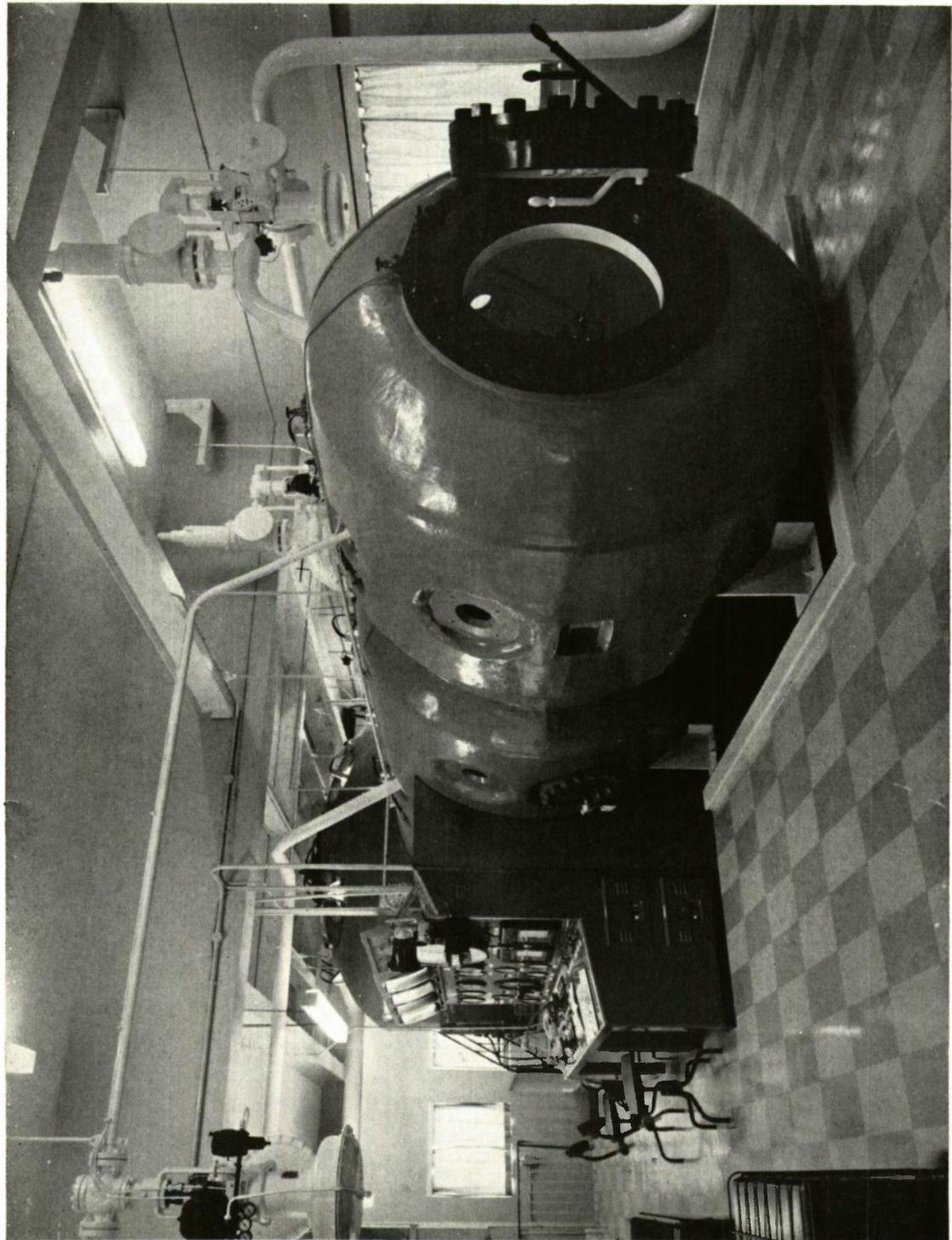
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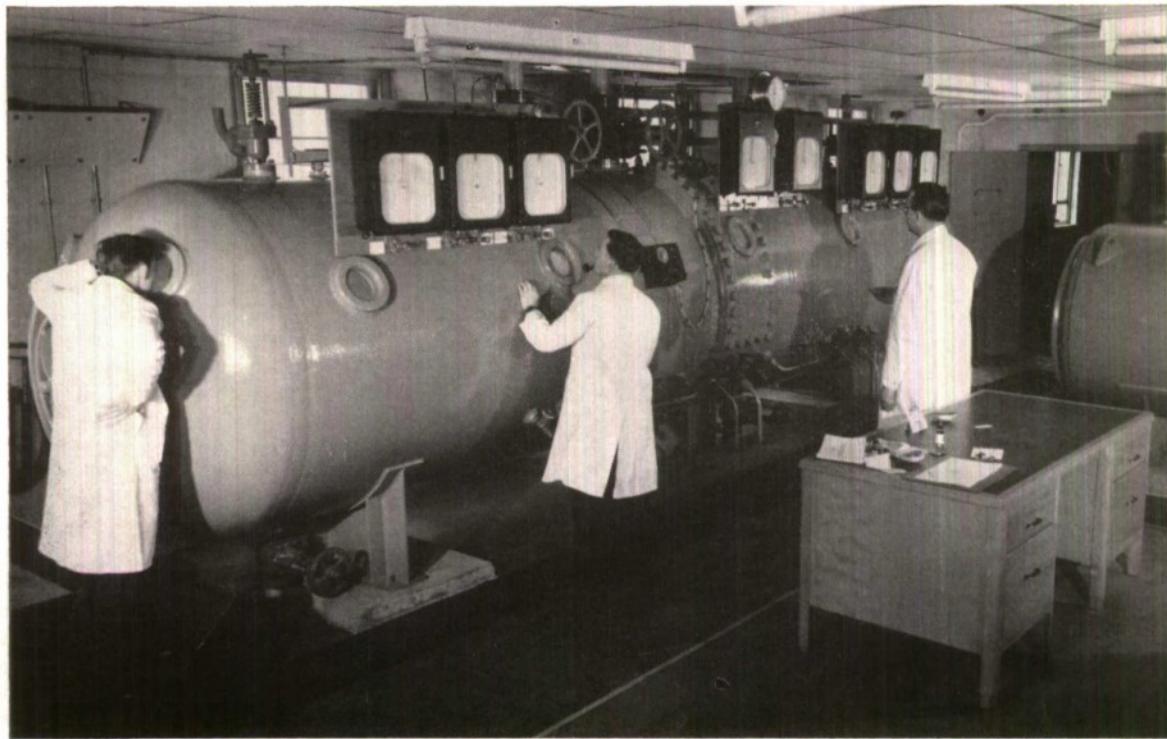
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*The Deep Diving Trials Unit at the Royal Naval Physiological Laboratory*



*The 800ft. Compression Chamber and attendants*

## PRESS OPEN DAY AT THE ROYAL NAVAL PHYSIOLOGICAL LABORATORY

A general invitation to representatives of the National and Scientific Press, Film, Radio and Television to visit the Royal Naval Physiological Laboratory, Alverstoke, on 2nd March 1965 met with a quite unexpected response. Some 62 members of the News world accepted the invitation. Their considerable interest in the work of the Establishment and its unique facilities was reflected in the world-wide coverage given to their reports in the national and technical Press and on film, radio and television programmes.

The visitors were present at one phase of the experimental programme, when two R.N. volunteers, Petty Officers D. Lott and A. Charlwood, entered the large dry compression Chamber and were taken down to a simulated depth of 800ft. Work on nitrogen narcosis was also explained, together with experiments being carried out on other aspects of underwater diving.

The Royal Naval Physiological Laboratory is staffed by Scientific and Experimental Officers and Scientific Assistants and there are also two Naval Medical Officers in attendance. A very close liaison is maintained with the Superintendent of Diving. By far the greatest amount of physiological research in the Navy is carried out at this Estab-

lishment where the facilities for diving research, and in fact all pressure work, are unique in this country and in many respects, in the world. The staff here have acquired knowledge and experience which is drawn upon by many widely different establishments, Navy departments and outside organisations. The Laboratory has a world-wide reputation, particularly among the N.A.T.O. countries, the United States in particular keep a constant flow of requests for information as to what is being done. Close contact is also maintained with Canada, Australia, New Zealand and India. Part of the function of the Laboratory is the training of Naval Medical Officers in Underwater Physiology, together with courses for Submarine Commanding Officers and for all New Entry Officers to the Submarine Service.

The main fields in which the Laboratory particularly specialises are as follows:—

### Submarine Escape

The whole of the present method is based on the fundamental work carried out here. The problems of ensuring the safety of escapes from sunken submarines was passed to this Laboratory and as a result of experiments the new methods of rapid



Visitors watching the progress of a dive in the Deep Diving Trials Unit

ascent without a breathing set (Free Ascent) were accepted and the 100 ft. Training Tank at H.M.S. *Dolphin* constructed. Recently, because of the increased operational depths of modern submarines, work has been going on to increase the depths from which submariners would have a reasonable chance of escape. This has involved very rapid compressions (to pressures equivalent to the order of 700 ft. of sea water in under 30 seconds) which avoids decompression sickness and to a very great extent inert gas narcosis. Special escape chambers for submarines, so that these methods can be introduced, are being designed and built. Recommendations have also been made as to what mixtures of gases shall be breathed before an escape.

#### Effect on Man of Explosions in the Water

A great deal of work has been done on the effects of such explosions on man. Physical parameters have been correlated with biological action and the knowledge is such that predictions can be made of effects when most parameters can be given. The use of explosive charges against men in the water has been thoroughly investigated and consideration given to the protection of our own personnel under such conditions. Considerable knowledge has been accumulated which would be available in an emergency.

#### Diving Problems

The major hazards of Deep Diving are decompression sickness, inert gas narcosis and oxygen poisoning. Some research on the latter problems

has been progressed, particularly from the point of view of prevention. The practical solution is to keep the partial pressure of oxygen breathed below a dangerous level and this Laboratory has been responsible for the recommendations adopted and the production of the necessary handbook of instruction, which is mainly physiological. As regards inert gas narcosis a great deal of work, including fundamental neuro-physiology, has been done. The current method of avoiding such narcosis is to carry out dives, where nitrogen narcosis could be a hazard, on helium/oxygen mixtures. This introduces new problems of decompression since the physical characteristics of helium (e.g. solubility in body fluids) are markedly different from other inert gases. A good deal of the effort of this Laboratory is directed to this problem for without its solution the greatly increased operational depths for divers—a Staff requirement—will not be achieved. This continuing research is meeting with success, and dives have been carried out to depths and with times on the bottom which have not been approached anywhere else in the world. To date R.N. volunteers have spent four hours at a depth of 600 ft. and two hours at 800 ft. The co-operation with the Admiralty Experimental Diving Unit on this project has been very close and invaluable.

#### Pulmonary Barotrauma

This is a hazard of decompression. Under certain circumstances there can be a pressure differential between gas in the lung, or portion of the lung, and the external pressure, leading to over distension. Gas can be forced into the circulation and lead to very serious consequences. A considerable amount of work aimed at providing knowledge of the cause and prevention of this condition has been carried out.

#### Other Projects

These include (a) measurements of the oxygen consumption of underwater swimmers so that a correct flow of gas from a breathing set can be known, (b) research into the ergonomics of man operated CO<sub>2</sub> absorption units for use in a submarine if power fails, (c) trials on Solar Stills and recommendations for improvement, (d) experiments in conjunction with the Naval Section of the Institute of Aviation Medicine on the effect of explosive ejection from an aircraft under water and (e) fundamental physiological work on respiratory problems associated with man under pressure.

The visitors were most impressed when shown the important new research installation known as the Deep Trials Unit which has now been completed at a cost of £200,000.

This is a research facility in which men and equipment can be subjected to pressures to the equivalent of 1125 ft. depth of sea water. Experi-

ments can be conducted in a dry atmosphere or underwater, in the latter case gas pressure to a maximum of 500 p.s.i. is exerted on top of the water to simulate the true depth required. Heating and refrigeration plant has been installed to create water temperatures from Arctic to Tropical conditions and closed circuit television coverage ensures trials subjects are kept under close supervision throughout experiments. The water clarity essential for television and photography is achieved by circulating the water through a filtration plant thereby removing dirt and other matter which inevitably finds its way into the unit.

The Unit is housed in a strongly constructed building on two main floors with an extension to the upper floor which is used as a loading bay for bulky equipment, and when not so used, becomes a rest room for subjects "surfacing" from a "dive".

The upper floor contains the operations room, laboratory, ready-use store, drying room, bathroom and the usual offices. The lower floor houses the heating, refrigeration and filtration plant, the main store and gas storage cylinders (capacity, 145,236 cu. ft. of gas at 4000 p.s.i.). These cylinders are charged from compressors housed in a building situated away from the unit to ensure minimum noise effect.

The pressure vessels are arranged in the form of a somewhat distorted letter "T", the vertical component being the diving vessel which is 20 feet high and 10 feet in diameter. Attached to the diving vessel and crossing it, are two air locks and a compression chamber which are situated on the operations room floor. The upper half of the diving vessel protrudes into the operations room and is the dry half of the vessel in which the diver's attendant is stationed. The lower half of the vessel continues down through the operations room floor through the lower section of the building and into a pit where it is supported. This part of the vessel is filled with 6000 gallons of water and has a buoyancy operated platform which is used to take the diver down and bring him up at the end of his dive. The largest of the three horizontally mounted vessels is the compression chamber into which the diver passes to do his decompression stops. This vessel is fitted with seats, bunks and central heating to ensure reasonable comfort during long decompressions, which for very deep dives, may take up to two or three days.

The two small vessels at either end of the assembly are referred to as air locks and are used for "locking in" the doctor, relief attendants, meals, etc., without altering the pressure in the larger vessels. Hand locks are also fitted to the Diving Vessel and Compression Chamber to enable small items such as medical instruments and liquid refreshment to be "locked in".



R.N.P.L. staff and an individual compression chamber

The pressure vessels are constructed from special low temperature steel, which for the Diving Vessel is  $2\frac{1}{2}$  ins. thick. The vessels are heavily lagged on the outside to maintain the desired temperature for each experiment.

Illumination, television, photography and visual observation is effected from outside the vessels through 5 in. diameter,  $1\frac{1}{4}$  in. thick armoured glass ports.

Operational control of the system is concentrated in a console situated in the operations room adjacent to the diving vessel and compression chamber. From this position the operator conducts the entire experiment, adjusting the pressure in the vessels to the required depth and pressure as shown by his gauges, by remote operation of the charging and exhaust valves. Television receivers enable him to observe activities inside the vessels and loud speaker communication keeps him in constant touch with all compartments. Part of the console is devoted to the Recorder who acts as "teller" and timekeeper to ensure that experiments are meticulously timed according to the scheduled programme. He is also responsible for subsequent analysis and logging the dive from the information recorded on time, pressure and tape recorders.

Although the primary function of the Deep Trials Unit is to carry out trials and experiments in order to progress the Royal Navy's underwater capabilities in diving and submarine activities, the facilities of the Unit will also be available to other Government departments who may need to make pressure tests to further their research.

In June this year H.M.S. *Reclaim* will be carrying out diving trials in the Mediterranean to depths of 600 ft. in order to test the already proved experimental dives made in both the 800 ft. Chamber and the Deep Diving Trials Unit.

# THE WAY TO THE STARS

By P. R. Wallis, B.Sc.(Eng.), A.C.G.I., A.M.I.E.E.  
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## SUMMARY

An examination is made of the two principal problems of interstellar travel on the basis of current physical knowledge. It is shown that the limitation of speed to less than that of light does not impose any restriction on the space-traveller himself as to how far he can go in a given time. It is shown that travel at mean speeds apparently faster than light will probably require anti-matter as a rocket fuel if moderate mass-ratios are to be used.

In the last few years we have seen the launching of the first artificial earth and solar satellites and the launching of men into orbit. There can be no doubt now that interplanetary travel, manned or unmanned, will enlarge not only our knowledge of the solar system but also of the Universe. Perhaps Man will in due course learn to live upon the more hospitable of the planets. Nor should we rule this out by applying present day economics; changed times will have changed economics.

It would be much bolder to predict interstellar travel and Man's colonisation of other planetary systems. Yet we can at least examine the magnitude of the problem in the light of present physical knowledge.

How far are the stars? The nearest star is  $\alpha$ -Centauri at a distance of 4.3 light-years, *i.e.* light takes 4.3 years to traverse the distance. Sirius, one of the brightest stars in the northern sky, is at 8.6 light-years. There are some 30 stars within 15 light-years. If we are to think of sufficient stars to find a tolerable planetary system, we may have to think of a few tens of light years.

But we all know that we cannot travel faster than light. Surely, then, we can rule out manned

travel over these distances; for a journey of, say, 30 light years, will we not take more than 30 years, more than a generation?

I propose to show that the argument is faulty and that this alone will not rule out manned interstellar travel. I will show that, in principle, I could travel even 1,000 light years in a mere 15 years. To develop this thesis I begin with a simple case without acceleration.

## Constant Velocity Space Traveller

Fig. 1 sets the scene. I shall assume that you stay behind on Earth. Your coordinate system  $S'$  is an inertial one in which the Earth, ignoring its orbital motion, can be regarded as at rest. I use the term "inertial" in the sense of the Special Theory of Relativity, *i.e.*, one in uniform rather than accelerated motion in which Newton's First Law holds.

At  $t'=0$  my space-ship passes Earth at speed  $v'$  and I synchronise my clock to read  $t=0$ . I also have an inertial coordinate system,  $S$ , in which my space ship is at rest at  $x=0$ . Let us suppose that I am heading for a star distant  $x'=d'$  from Earth.

The Special Theory then gives <sup>(1)</sup> the relationship between the coordinates  $x$ ,  $t$  and  $x'$ ,  $t'$  of any event:

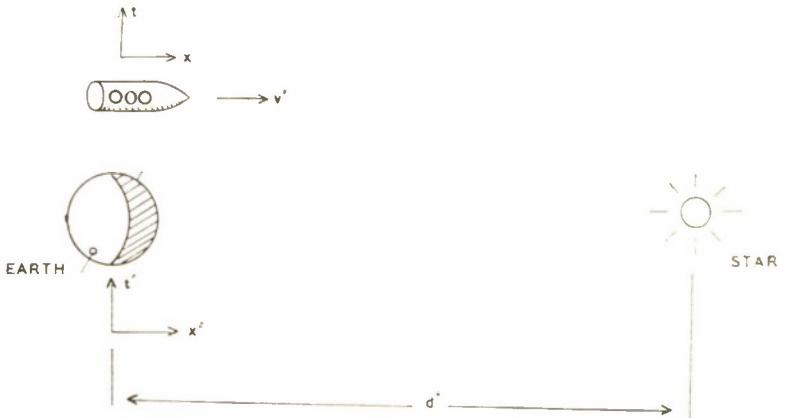


Fig. 1.  
Constant velocity travel.

$$x = \beta(x' - v't') \quad \dots (1)$$

$$t = \beta\left(t' - \frac{v'x'}{c^2}\right) \quad \dots (2)$$

where

$$\beta = \frac{1}{\sqrt{1 - (v'/c)^2}} \quad \dots (3)$$

and  $c$  is the speed of light *in vacuo*.

You will expect me to reach my destination at time

$$t' = d'/v'. \quad \dots (4)$$

The Special Theory also shows that a velocity  $v'$  numerically greater than  $c$  leads to an unacceptable paradox. It follows that the time to cover the distance  $d'$  is, to you, always in excess of  $d'/c$ .

We find the coordinates of my arrival in my system  $S$  by substituting  $x' = d'$  and  $t' = d'/v'$  in (1) and (2).

Thus  $x = \beta(d' - v'd'/v') = 0$ , which is clearly correct, and

$$\begin{aligned} t &= \beta(d'/v' - v'd'/c^2) \\ &= \beta \frac{d'}{v'} (1 - (v'/c)^2) \\ &= \frac{d'}{v'} \cdot \frac{1}{\beta} \quad \dots (5) \end{aligned}$$

Equation (5) gives an elapsed time  $\beta$  times smaller than Equation (4).

For low values of  $v'$  there is no disagreement between our assessments of the time but, if  $v'$  is large and approaching  $c$  in magnitude, the difference will be great. Thus we find that I can make my travel time as small as I like by increasing  $\beta$ .

This odd result can be made clearer by calculating the distance to be covered as it appears to me in  $S$  at  $t=0$ . To do this we set  $t=0$  in

Equation (2), obtaining

$$t' = v' \cdot x'/c^2$$

and then substitute this with  $x' = d'$  into (1), whence

$$\begin{aligned} x &= \beta(d' - v' \cdot v' \cdot d'/c^2) \\ &= d'/\beta. \end{aligned}$$

Thus to me the distance to go is as much smaller as the time; my assessment of our relative velocity is the same as yours.

These results are not without experimental confirmation, though as yet confined to the field of particle physics where alone such high velocities are to be encountered. In the laboratory the mean lifetime of slow  $\pi$ -mesons has been determined to be  $2.6 \times 10^{-8}$  seconds <sup>(3)</sup>. Even at the speed of light a particle could only travel eight metres in this time. Yet it is known that the high energy  $\pi$ -mesons observed at sea level originate high up in the atmosphere from collisions of cosmic ray primary particles. This problem is resolved by the dilation of the lifetime when observed from a coordinate system in relative motion. For the particles to be able to travel 30 kilometres instead of eight metres,  $\beta$  must be of the order of  $4 \times 10^8$  implying a particle velocity only 10 metres per second less than that of light. Such velocities and energies are frequently found in cosmic ray phenomena.

However a human space-traveller cannot be expected to reach velocities near to that of light without difficulty so we must consider the more complicated case in which I start from rest on Earth and finish at rest in the new star system. It will also help to avoid the philosophical difficulties which can be found when only observers in uniform motion are considered, e.g., that I can never return to Earth to re-check our clocks. I shall consider at first a constant magnitude of acceleration throughout my journey.

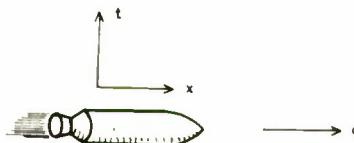
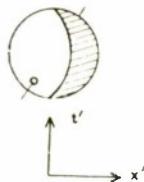


Fig. 2.  
Accelerated travel.



### Constant Acceleration Space Traveller

The situation is shown in Fig. 2. I now start at rest at  $t=t'=0$  on Earth ( $x'=0$ ) and accelerate uniformly with a magnitude  $g$  for time  $T'$ , followed by an equal deceleration for an equal time.

We immediately run into a difficulty that in the Special Theory of Relativity acceleration is not an invariant and two observers in relative motion will not agree on its magnitude. We shall choose therefore a constant "relativistic" acceleration, which is that measured in the rest frame of my space-ship. This "rest frame" is defined as the inertial frame in which my space-ship is, momentarily, at rest. So I shall be experiencing a constant acceleration  $g$ .

In the Earth's frame, however, this acceleration is assessed differently. It can be shown <sup>(1)</sup> using the Special Theory of Relativity that a constant relativistic acceleration leads to a differential equation for the space-ship:

$$\frac{d}{dt'}(\beta v') = g,$$

where  $\beta$  is given by (3) but is no longer a constant. Substituting and integrating we obtain

$$\frac{v'}{\sqrt{1-(v'/c)^2}} = gt' + K,$$

where  $K=0$  if my space-ship starts at rest at  $t'=0$ . Re-arranging this equation gives

$$v' = \frac{gt'}{\sqrt{1+(gt'/c)^2}}. \quad \dots (6)$$

Substitution in Equation (3) gives a more convenient form for  $\beta$ :

$$\beta = \sqrt{1+(gt'/c)^2}. \quad \dots (7)$$

Differentiating (6), we note in passing that the acceleration as measured by Earth can be written as

$$g' = \frac{dv'}{dt'} = g/\beta^3.$$

Integrating (6) again, we obtain

$$x' = \frac{c^2}{g} \left[ \sqrt{1+(gt'/c)^2} - 1 \right].$$

It can be shown that this reduces to the Newtonian form  $x' = gt'^2/2$  when  $gt'/c$  is small.

If we assume these equations to hold up to time  $T'$  and that the acceleration is then reversed, we find the total distance traversed in time  $2T'$  to be

$$d' = \frac{2c^2}{g} \left[ \sqrt{1+(gT'/c)^2} - 1 \right], \quad \dots (8)$$

at a mean speed of:

$$\frac{c^2}{gT'} \left[ \sqrt{1+(gT'/c)^2} - 1 \right]. \quad \dots (9)$$

However large  $gT'$ , this quantity cannot exceed  $c$ , as found in the previous case.

At any instant during the flight my time scale will differ from that on Earth due to the relative velocity. An interval  $dt$  in the space-ship's rest frame will appear in the Earth's as

$$dt' = \beta dt.$$

Thus the time elapsed on board corresponding to  $T'$  on Earth is

$$T = \int_0^{T'} \frac{dt'}{\beta}.$$

Using (7), we find

$$T = \frac{c}{g} \sinh^{-1}(gT'/c). \quad \dots (10)$$

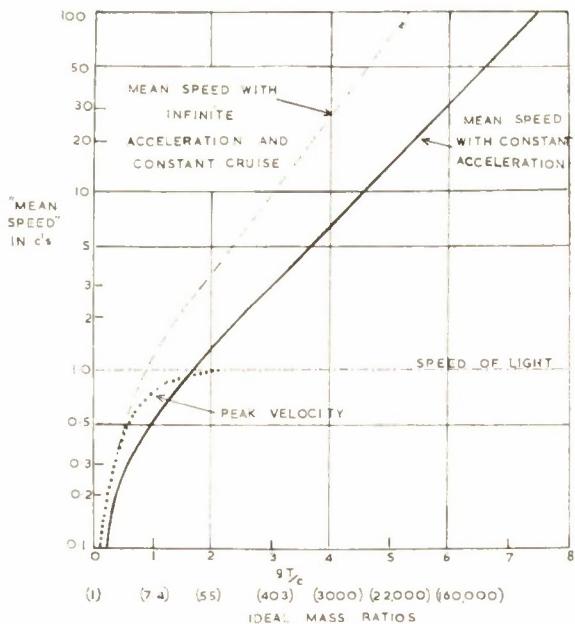


Fig. 3. "Mean speed" over the distance as a function of  $gT/c$ .

Substituting (10) in (8) it appears to me in my space-ship that I have traversed a total distance in time  $2T$  of

$$d' = \frac{2c^2}{g} \left[ \cosh(gT/c) - 1 \right] \quad \dots (11)$$

at a "mean speed"

$$\frac{c^2}{gT} \left[ \cosh(gT/c) - 1 \right]. \quad \dots (12)$$

This last result is illustrated in Fig. 3. It can be seen that providing  $gT/c$  is large enough, I can achieve a mean speed considerably in excess of that of light. To indicate the numerical values associated, it is observed that an acceleration of one Earth gravity,  $g_0$ , for one year leads to a value for  $gT/c$  close to unity. Fig. 4 shows the distances given by Equation (11) which can be reached in any given number of years using this amount of acceleration.

These results are astounding and one is inclined at first to doubt their validity. Surely the Special Theory of Relativity cannot tell me that my speed is greater than that of light, as suggested by (12)? Well of course it doesn't. At any instant during my journey I can assess the velocity relative to the Earth of my space-ship, perhaps by observing the doppler frequency shift of a signal from Earth and using the formula

$$\frac{f}{f'} = \sqrt{\frac{1-(v/c)}{1+(v/c)}}.$$

The answer will be the same as found by substituting (10) into (6), i.e.,

$$v = c \tanh(gt/c).$$

The peak value reached at time  $T$  is shown dotted in Fig. 3 and it is apparent that it does not exceed  $c$ .

It is an entirely different matter to divide the total distance in Earth terms by the elapsed time in my accelerating space-ship, hence my use of parentheses for "mean speed". The Special Theory of Relativity does not attempt to set up equations for accelerated frames of reference (which was why we had to introduce the succession of rest frames). The General Theory of Relativity instead regards all frames as acceptable and it can be shown that the simple rule for the Special Theory that

$$v \neq c$$

need not then apply (see, for example, p.356 of Reference 2). Nevertheless it is this mean speed that is of interest to me in my travels and I have demonstrated that I can in principle achieve "faster-than-light" travel without resorting to the space warps of science fiction and fully in accordance with the Theory of Relativity.

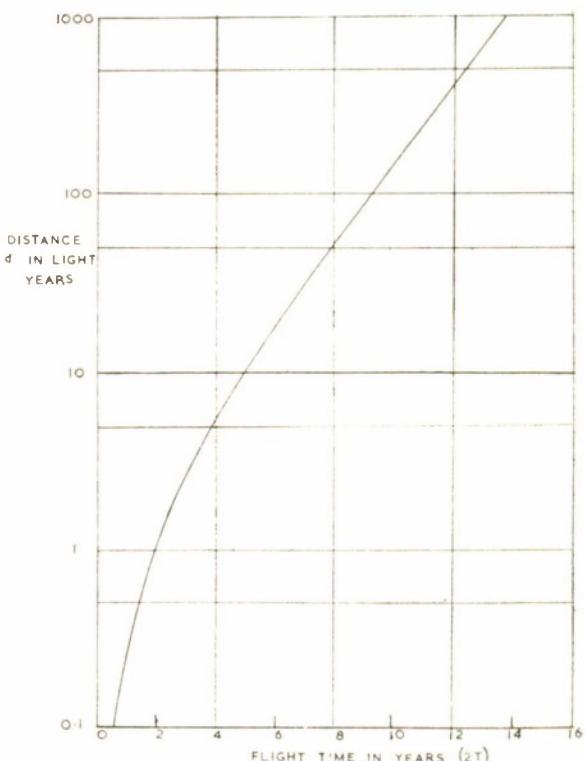


Fig. 4. Distance travelled using an acceleration of one Earth Gravity

## Generalisation to include an Intermediate Cruise

The above analysis can readily be generalised to include an acceleration-free period. If we postulate that this lasts time  $\tau$  according to me, then it will be assessed on Earth as lasting time  $\beta\tau$ . The additional distance  $D'$  travelled at the peak speed  $v'$  is found, using (6) and (7), to be

$$D' = gT\tau$$

In terms of my time measure this, using (10), is

$$D' = c\tau \sinh(gT/c)$$

and must be added to (11) to give the total distance travelled in time  $2T + \tau$ . In Fig. 5 an example is given for an acceleration of one Earth gravity. The lines branching off correspond to the case when any desired period of cruise is used. The figures against each branch are the acceleration time in years; there is, of course, an equal time for deceleration (unless allowance is made for expansion of the Universe).

It is clear that this technique extends the time of flight. However, as will be shown, it reduces the total energy required to achieve a given mean speed of travel.

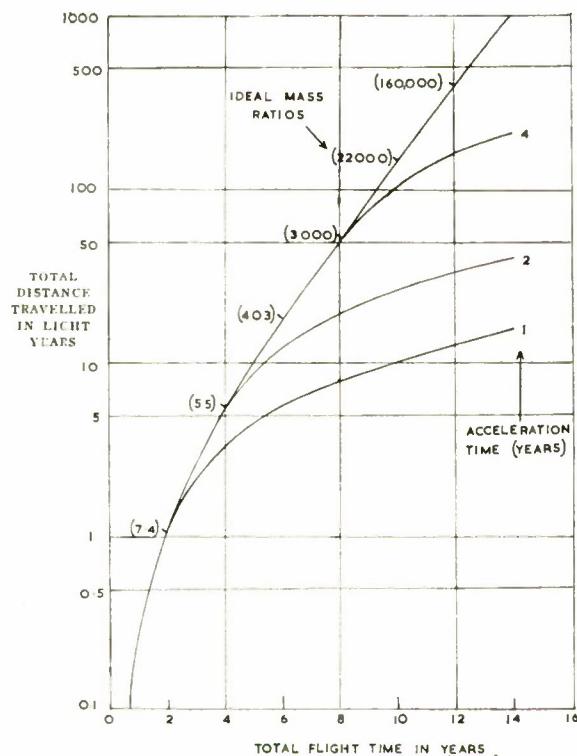


Fig. 5. Distance travelled using intermediate cruise and an acceleration of one Earth Gravity.

## The Clock Paradox

If after reaching my destination I return to Earth in a similar manner, I shall not find agreement on Earth with my assessment of the elapsed time. Indeed I could expect to return from a long flight to an Earth perhaps centuries older. This is a necessary consequence of Relativity; so far there is no paradox, merely an unexpected result.

The notorious clock paradox arises only when it is claimed that, to an observer in my space-ship, it is the Earth that has left on a journey and eventually returned; hence the Earth will consider me to be older. We cannot both be older, hence the paradox.

But my adoption of an accelerated space-ship rather than one at constant velocity makes it clear that my position and that of an Earthman are not symmetrical. I am accelerating and you are not; so we cannot validly interchange our viewpoints in Special Relativity. Indeed by an application of the General Theory of Relativity it may be shown (2, p.354) how my assessment of earth-time is affected by my acceleration if I use an accelerated reference frame. Thus it is confirmed that the difference between my clock and yours on my return will be a real one.

## Energy and Propulsion Problems

We now look at the practicability of achieving the accelerations and durations discussed. In the first place we note that in order to leave the ground our initial thrust must correspond to marginally more than one earth-gravity. Once however we are in an orbit which no longer intersects the Earth or its atmosphere there ceases to be a minimum acceptable thrust. Only chemical rocket systems provide at the moment the thrust necessary to reach orbit but we can conceive of alternatives (e.g. winged hypersonic ramjets using chemical or nuclear power) without difficulty. Once in orbit we can look even more widely for our motor.

I shall show first of all that a chemical rocket will not do. Let us consider a rocket of initial mass  $M_0$  using a fuel of specific impulse  $S$  to give a constant acceleration (in space-ship terms) of  $g$ . (We adopt the practical units for  $S$  of lbs. weight thrust per lb. of fuel consumed.) The rocket thrust will be

$$g_0 S \frac{dM}{dt}$$

where  $g_0$  is the acceleration under Earth's gravity. Applying Newton's Second Law we obtain, to the first order

$$gM = g_0 S \cdot \frac{dM}{dt}$$

Integrating, we find at time  $2T$ :

$$\frac{M_0}{M_{2T}} = \exp \left[ 2 \cdot \frac{gT}{c} \cdot \frac{c}{g_0 S} \right]. \dots (13)$$

Consulting Fig. 3, we note that to travel "faster than light" we require  $gT/c$  to exceed about 1.6, which implies a mass ratio greater than

$$\exp \left[ 3.2 \frac{c}{g_0 S} \right].$$

For a typical value of  $S$  of 300 seconds, it is clear that our mass ratio will be impossibly large.

We must obviously do a great deal better than this if interstellar travel is to be practicable, so I shall assume that nuclear power is available. I must also compute the available impulse in a manner consistent with relativity if the exhaust velocity is high.

Let us consider the consumption of 1 gram of fuel and assume that it is utilised as follows:

$$1 \text{ gram of fuel} \left\{ \begin{array}{l} n \text{ grams of available energy} \\ k_0 \text{ grams (rest mass) of exhaust material at velocity } v \\ 1-n-k_0 \text{ ash rejected at zero velocity.} \end{array} \right.$$

The exhaust will have an inertial mass

$$k = \frac{k_0}{\sqrt{1-(v/c)^2}}$$

where

$$n = k - k_0$$

whence

$$v = c \sqrt{1 - (k_0/n + k_0)^2}.$$

The relativistic impulse given to the space-ship is:

$$P = kv = (k_0 + n)v = c \sqrt{n^2 + 2nk_0}. \dots (14)$$

To obtain the maximum possible impulse per gram of fuel we wish to increase both  $n$  and  $k_0$ . The latter cannot exceed  $1-n$ , *i.e.* when all the ash is used as exhaust material, and (14) then becomes:

$$P = c \sqrt{2n - n^2} \dots (15)$$

If we use none of the ash as exhaust material, *i.e.*  $k_0=0$ , which corresponds to a photon-drive (or conceivably a neutrino-drive), Equation (14) takes a smaller value

$$P = cn \dots (16)$$

Equations (15) and (16) are identical however when  $n=1$ , *i.e.* all the mass can be converted to energy.

Let us take first this "ideal" case of  $n=1$ . The specific impulse then becomes

$$S = c/g_0$$

and, using (13), the final "ideal" mass ratio becomes:

$$\frac{M_0}{M_{2T}} = \exp (2gT/c) \dots (17)$$

The ideal mass ratios are given in brackets against the abscissa of Fig. 3. Mass ratios of the order of 10 to 1 per stage are used in current rocket technology so, using the multi-stage principle, "faster-than-light" travel appears to be feasible.

As an example consider a journey of 30 light-years, to be completed in a total time of 11 years. This is a mean speed of 2.73c. Fig. 3 shows that this requires a  $gT/c$  of 2.9 and therefore a mass ratio, by (17) of 330. The acceleration required is 0.52 earth-gravities.

As an alternative we can use a cruising period. If our initial acceleration is one earth-gravity, we see from Fig. 5 that we can complete a 30 light-year journey in 11 years using two years acceleration, seven years cruise and two years deceleration. The required mass ratio is 55 and as this remains constant on any branch, these are shown in brackets on Fig. 5. If we were able to proceed to the limit and use an infinite acceleration and deceleration, we would achieve a  $gT/c$  of 1.75 and a mass ratio of 33. The upper line on Fig. 3 indicates the "mean speed" achieved in this limiting case as a function of the ideal mass ratio.

In general we shall be more efficient in terms of mass ratio the greater the proportion of the time spent in unpowered flight. However there will naturally be physiological and mechanical limitations on the usable acceleration, and indeed there may be more difficulty in designing for the requisite mass ratio if the accelerating forces are high.

A photon (or neutrino) drive powerful enough for an acceleration of one earth-gravity will require some advance in technique. The power of the light source turns out to be  $3 \times 10^{13}$  ergs/second per gram of the space-ship. In more usual units this is three Megawatts per gram or three million Megawatts per ton of space-ship!

A more fundamental difficulty, however, lies in our assumption of complete consumption of the mass of the fuel. In nuclear fission we are able to obtain only about 0.1% of the total energy, *i.e.*  $n=0.001$ . Using a photon-drive this would reduce the specific impulse by a factor of 1,000. However this can be ameliorated by exhausting all our nuclear ash in accordance with Equation (15), giving a loss of only 22 times. This would be optimistic, however, if it was not possible to exhaust all the ash at the same velocity in the appropriate direction. Suppose, for example, we use the naturally

recoiling fission fragments (which carry the major part of the energy). If only rear-ward directed fragments contribute to the thrust and these are randomly oriented we not only have to set  $k_0 = (1-n)/2$  in (14) but divide by two to allow for the orientations. Thus our impulse becomes  $c\sqrt{n}/2$  which is less than ideal by a factor of 63.

With fusion reactions a somewhat larger proportion of the energy can be made available. For example, if we burn Hydrogen 1 into Helium 4 we obtain about 0.7%. In both these cases however we can expect astronomical mass ratios for astronomical journeys.

If, then, we turn disappointed away from fission and fusion, what is left? The only known reactions which lead to the total annihilation of rest mass involve the collision of a particle with its so-called anti-matter particle, for example an electron-positron collision. We may therefore conceive our interstellar rocket as two enormous tanks, one filled with liquid hydrogen, the other with liquid anti-hydrogen. But we have not yet the scientific ability to manufacture anti-matter in quantity; it is only with particle accelerators achieving particle energies of several thousand MeV that we can make a few anti-protons at a time.

There is also the problem of storing the anti-matter once made. A container made of ordinary matter is likely to be unusable. If the anti-matter is at a very high temperature and almost completely ionised, storage might be possible in magnetic bottles, but it would probably be impossible to prevent leakage of neutral atoms and the density would be very low. But we should not despair; any nuclear energy seemed impossible 60 years ago.

The other possibility we must briefly explore is the attractive one of finding our fuel in space as we go. Over 90% of the total mass of gas and dust in the space between the stars of our galaxy is made up of hydrogen. If we can use this for our fusion reaction, we can work with a mass ratio of unity.

If the density of interstellar gas is  $\rho$  grams per cc. and we are moving through it at velocity  $v_1$ , using a collecting area  $A$ , we shall sweep up

$$m_0 = \beta_1 \rho A v_1 \text{ grams}$$

per space-ship second, where

$$\beta_1 = \frac{1}{\sqrt{1-(v_1/c)^2}}.$$

The  $\beta$  term allows for the Lorentz contraction. As the gas arrives with kinetic energy it has a total inertial mass  $m_1 = \beta_1 m_0$ . If we can convert into energy a proportion  $n$  of the rest mass  $m_0$ , then our exhaust will have a rest mass  $(1-n)m_0$  and a velocity  $v_2$  where its inertial mass is

$$m_2 = \beta_2 (1-n)m_0,$$

with

$$\beta_2 = \frac{1}{\sqrt{1-(v_2/c)^2}}.$$

Conservation of energy requires that  $m_2 = m_1$ . The thrust obtained is

$$P = m_2 v_2 - m_1 v_1,$$

and using the earlier relations this becomes:

$$P = \rho A c^2 \sqrt{\beta_1^2 - 1} [ \sqrt{\beta_1^2 - (1-n)^2} - \sqrt{\beta_1^2 - 1} ].$$

Provided  $n$  is small and  $\beta_1$  is not too near to unity, this gives approximately:

$$P = \rho A c^2 n. \quad \dots (18)$$

Equation (18) shows that the system can provide a constant thrust. Though increased speed increases rapidly the amount of gas consumed, the efficiency of the momentum mechanism falls as the mass velocities approach the speed of light.

This result does not apply when  $v_1$  is small and it can be shown that the thrust is then given approximately by

$$P = \rho A c v_1 \sqrt{2n}. \quad \dots (19)$$

which tends to zero as  $v_1$  tends to zero. Comparison of (18) and (19) shows that the thrust cannot be developed until the space-ship speed reaches some 5 or 10% of that of light. Once achieved, however, we can expect an acceleration of the order of

$$\frac{\rho}{\rho} \cdot n \cdot \frac{c^2}{L}$$

where  $\bar{\rho}$  is the mean density of the space-ship and  $L$  its length, the cross sectional area being assumed to be  $A$ . If an acceleration of about one earth gravity is to be achieved with a ship of length 1 km, then the density of the ship compared with that of the gas through which it travels must not exceed about  $10^{11}$ . It is thought however that the density of interstellar gas clouds is many orders of magnitude less than would be required by the above condition and we must regard the interstellar nuclear ramjet as a doubtful starter.

The less ambitious form of ramjet in which we carry our own nuclear fuel but use interstellar gas as our working fluid also turns out to be disappointing, with a specific impulse no better than (14).

The possibility of using the radiation pressure of the sun and terminal star also leads to a discouraging conclusion. A very low density of "sail" would be required to achieve useful accelerations and then only while close to the sun. For example a sail density of about  $10^{-3}$  grams per sq. cm.

would only just balance the gravitational attraction of the sun. Half this density and we would only obtain about  $0.6 \text{ cm/sec}^2$  at the radius of the Earth's orbit, reducing as distance increased.

Unless we can devise accelerating systems based on electrical, magnetic or even gravitational fields, which I shall not attempt to predict, we must fall back upon the antimatter-fuelled rocket if high-speed interstellar travel is to be achieved.

### Conclusion

We have looked tentatively at the problem posed by interstellar travel from the standpoint of the physical knowledge of to-day, reaching the following conclusions.

Firstly, we should not be deterred by the fact that we cannot exceed the speed of light. This will prevent those who stay on earth from receiving in their own lifetimes first-hand reports about any but the nearest stars. It will not however serve as any fundamental limit to the space-travellers themselves.

Secondly we may conclude tentatively that the achievement of really high speed travel with reasonable mass-ratios is likely to demand the use of anti-matter as rocket fuel, with all the uncertainties and difficulties this implies. If we are limited to fusion or fission nuclear power sources, we are unlikely to achieve travel at other than low speed without impractically high mass-ratios.

Use of interstellar gas as a working medium turns out to be of small value as the efficiency with which thrust can be obtained reduces as the velocities near that of light.

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The Editor

Journal of the Royal Naval Scientific Service

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Empress State Building

London, S.W.6

# *The Digital Computer in Nuclear Training at Royal Naval College, Greenwich*

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*Department of Nuclear Science and Technology*

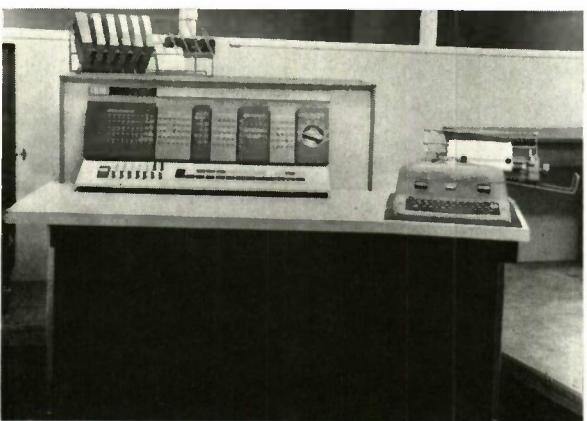
In February 1962 an *IBM* 1620 Digital Computer was installed in the Department of Nuclear Science at Royal Naval College for use in the training of personnel concerned with the nuclear submarine programme. The original system consisted of a 1620 basic computer with paper tape reader and punch; in order to reduce the pressure on machine time an *IBM* 870 card/tape unit was installed in October 1962, and subsequently used for the preparation of source tapes and a variety of other off-line functions.

It was very soon apparent that the limited core capacity (20,000 digits) of the *IBM* 1620 was inadequate for many of the programmes being written and in August 1964 an *IBM* 1311 disk drive unit was installed giving a back-up disk storage capacity of two million digits on each disk, and a considerably improved performance in programme processing.

The computer has proved of great value in many aspects of the work of the Nuclear Science Department and particularly in connection with the Nuclear Advanced Course, a one year post-graduate course which includes a three month Design Study of a nuclear reactor system. The scope and depth of this study have been greatly increased by the use of computer programmes, many of which have been written by the students. A considerable and growing library of programmes is now available for the use of future Design Studies.

Courses in *Fortran* programme writing are held at regular intervals and have proved popular with other departments of the College as well as a number of Admiralty departments and establishments. Other main uses within the department are in automatic data processing and in connection with research projects and, not least, as an elegant training aid in computer demonstrations of solutions to specific reactor problems.

The time available for the *Fortran* programming course is approximately 25 hours on five consecutive days, with some opportunity for additional



*IBM 1620 Data processing system*



Paper tape reader and punch on left. IBM 1311 Disk drive unit on right.

practical work in the evenings. This 25 hours is carefully allocated to lectures, tutorial and practicals; the students are divided into small groups for the practical work, ideally of two but for large courses this may have to be increased to a maximum of four. The objectives are first, to teach the fundamentals of *Fortran* programme writing, with the minimum of machine language instructions required to be able to operate the computer; second, to take each student through the complete processing and operating routine, including error diagnosis, using a programme which he has written himself. In general this has been achieved by the end of the third day; the remaining practical/tutorial time is then available for either extending the initial programme to include more complex logic or to write a more ambitious programme making use of the more advanced techniques which are described in the later lectures.



The "off line" equipment.

Handouts have been produced to replace the *IBM* handbooks, which are not suitable for the beginner; these include descriptions of elementary and advanced programme writing techniques and operating procedures for the *IBM* 1620/1311 Monitor System, and have proved successful in eliminating many of the frustrating errors which are liable to occur in the early stages of computer programming and operating.

The success of these courses can be judged by the performance of the Advanced Course students in applying computational techniques in their Design Study work, which follows hard on the computer course. The problems to be investigated include studies in Reactor Physics, Heat Transfer and Radiological Protection; student programmes have been written in each of these fields with success. For example, in Reactor Physics there is a four-group neutron diffusion theory analysis of a multi-region reflected core in cylindrical geometry; this uses a difference equation technique to evaluate eigenvalue and flux profile. Other physics studies include a fuel cycle analysis programme based upon perturbation theory and investigations of burnable poison and Xenon concentrations and their time variation. In heat transfer, programmes have been written to generate core temperature profiles and a preliminary study of heat exchanger design has been made.

Work has also been done by the staff of the department towards providing programmes for student use where the complexity of the programme precludes its development during the design study. Examples here are a transport theory analysis of the unit cylindrical cell using the *P*3 spherical harmonics approximation, to generate flux profile and disadvantage factor, and a two group two region diffusion theory analysis of a totally reflected cylinder using the method of buckling iteration. These programmes require extensive ranges of the Bessel functions *I*, *J*, *K* and *Y* up to fourth order and these are generated within the programmes for both large and small argument. The first programme is part of a general study of analytical methods for the unit cell which includes collision probability and Monte Carlo techniques.

An example of the use of the computer for data processing is provided by a programme which accepts the output of an automatic foil counter, in which batches of irradiated foils from the *Jason* reactor have been counted. This typifies the integration of the facilities of the department in student experiments; in measuring a flux profile in the thermal column of *Jason* the students make use of reactor, automatic foil counter and digital computer in producing the final result. A second

example of this is the processing of the output of a multi-channel pulse height analyser used for gamma scintillation spectrometry and activation analysis, also incorporated into student experiments.

As a training aid the *IBM* 1620 has found application in a number of subjects and its use in this respect is steadily increasing. The problems which can best be demonstrated are basically mathematical evaluations which depend either upon repetitive calculations or have a number of input parameters which require to be varied independently. A computer demonstration of the calculation has an impact which cannot be equalled by any amount of blackboard work or handout presentation and has the added advantage that the student may choose the input data and, in many instances, the logic of the calculation himself. It is, of course, necessary to programme the problem with care in order for this to be successful.

In Reactor Physics a typical demonstration is a calculation of the infinite multiplication factor for a heterogenous assembly of fuel, moderator and cladding in which the variables are fuel pin radius, moderator radius and enrichment and the ingredients are specified in the initial input data. Other Physics demonstrations investigate radioactive equilibrium, homogeneous multiplication factors and two-group flux calculations. In Control Theory programmes have been written to demonstrate the principle of convolution and the generation of normalised Bode diagrams. Reactor shielding programmes are also used as student demonstrations.

The computer has played a significant part in the research of the department to date; an investigation into the streaming of neutrons in ducts has made extensive use of computer programmes to develop a theoretical model with which experimental data can be correlated. A random binary code generator and a binary code statistical cross-correlation programme are used in conjunction with an investigation into the use of

correlation techniques in reactor control theory. Some preliminary investigations of theoretical models for the calculation of neutron distributions in reactor systems have also been programmed.

Mention must finally be made of non-nuclear computer activities; other departments of the College have access to the *IBM* 1620 and a steadily increasing demand on time has been evident. There is a teaching commitment in the department of Physics and Electrical Engineering with an emphasis on digital techniques; other departments, notably Applied Mechanics, are mainly interested in research applications. Some work on tactical problems has been done at the instigation of the Woolwich Tactical School; low level bombing tables have been produced for H.M.S. *Excellent* and the Hydrographer has made use of our training courses and facilities for work on triangulation and other problems. A lecture on Critical Path Scheduling, followed by a demonstration of a *PERT* programme, is given as part of the one week computer course.

The use of a small digital computer in a teaching role is not often emphasised; indeed there is a tendency in University and technical departments for this teaching role to become subsidiary to the demands of data processing and research. Experience at the College has made it quite clear that an understanding of digital computer techniques, which is most readily acquired by learning to programme a particular computer, is of great value to the student of Nuclear Engineering and this must be true for all students of Engineering who are destined eventually for design work, for most scientists and for the users of weapons systems. In this role the small computer has an advantage over its larger brother, in that no full-time operating staff need be interposed between student and computer. He can programme, operate and diagnose errors with a minimum of assistance; he soon begins to look at problems with a new, computer-orientated outlook and can see possibilities of solution to problems which would otherwise have been dismissed as "too difficult."



# A SEMICONDUCTOR LASER ARRAY

By R. F. J. Broom, B.Sc.

*Services Electronics Research Laboratory*

## Introduction

The beam emitted from a GaAs diode laser subtends an angle of  $30^\circ$  in a sagittal plane (*i.e.*, perpendicular to the junction plane) and  $10^\circ$  in a tangential plane (*i.e.*, parallel to the junction plane). Therefore for most applications a lens must be used to collimate the beam and to accept all the light this lens must have an aperture of  $f/2$ . In order to obtain peak power outputs greater than 100 watts it is necessary to increase the area of the diode to several square millimetres, creating difficulties with the electrical drive circuit. The length of the emitting surface of the junction must also be increased to several millimetres making the focal length and diameter of the collimating lens unacceptably large for beam widths of  $1^\circ$  or less. The use of a number of small area laser diodes connected electrically in series and optically in parallel simplifies the drive system and reduces the volume occupied by the collimating optics. A method of producing, in compact form, a parallel beam from an array of lasers and the construction of a practical system is described in this paper.

## Collimating Optics

Consider the plane-cylindrical lens system shown in Fig. 1. The lens  $L_1$  has the axis of its curved surface in a tangential plane and  $L_2$  the axis of its curved surface in a sagittal plane. To accept all the light in a sagittal plane  $L_1$  must have an effective aperture of  $f/2$  but to form a narrow beam in this plane it need only have a short focal length because the thickness  $t$  of the emitting region of the laser is less than  $10\mu$ . In a tangential plane  $L_2$  defines the largest dimension of the beam but it need only have an effective aperture of  $f/6$ . Hence the use of cylindrical lenses enables the optical system to be compressed in two dimensions by exploiting the narrowness of the source and the relatively narrow beam in a tangential plane. An array can be constructed in the manner shown in Fig. 2.

A second laser (2) may be added beneath the original unit with a second cylindrical lens  $L_1'$  and  $L_2$  extended downwards. Similarly lasers 3 and 4 may be placed to the left involving an extension of  $L_1$  and  $L_1'$  and an additional lens  $L_2'$ . The minimum area occupied by each element of the

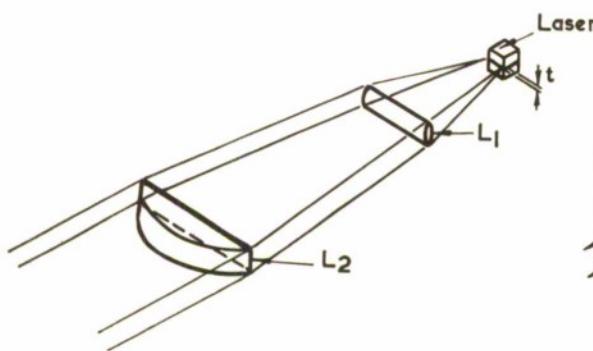


Fig. 1.

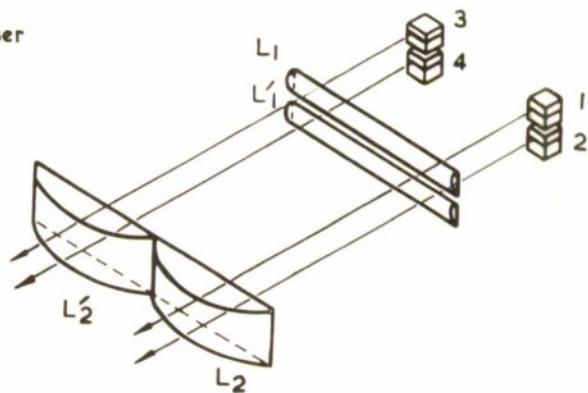


Fig. 2.

array is dependent on the required beam width. For a  $1^\circ$  beam width and a 1 mm source length the area occupied by each element is  $0.3 \text{ cm}^2$ , compared with  $9 \text{ cm}^2$  if spherical lenses were employed.

### Construction of an Array of 10 Lasers

A linear array of ten lasers has been designed on the basis of the above arguments. Each laser diode is 2 mm long and 1 mm wide across the emitting surface. Preliminary measurements on single units indicate that the array will give a peak light output of 1 kW and a mean output approaching 10 watts. The method of construction is shown in Fig. 3, for clarity only two elements are drawn.

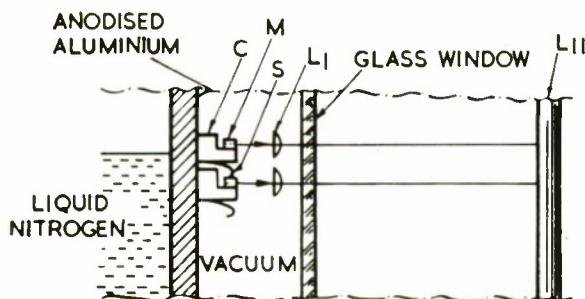


Fig. 3.

Each laser diode M is soldered to a copper block C which also supports a plane-cylindrical lens  $L_1$  of focal length 6 mm. The lens mount is fitted with means for focussing and alignment so that all 10 beams may be adjusted for parallelism with one another. The copper blocks are clamped to an anodized aluminium heat sink cooled with liquid nitrogen. The anodizing gives good thermal contact but isolates the blocks from one another electrically so that the lasers may be connected in series by means of the springs S. Focussing of the beam in a tangential plane is achieved by the lens  $L_{11}$

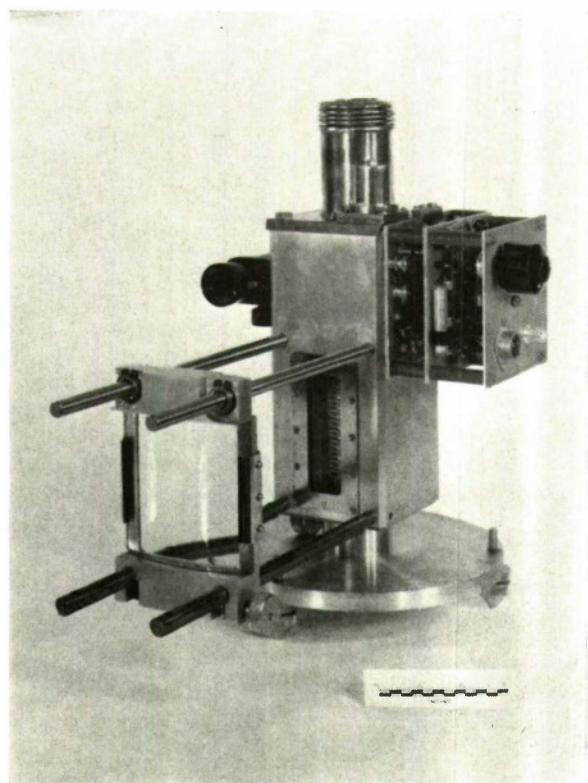


Fig. 4.

of 20 cm focal length placed outside the dewar vessel. Thus the largest dimension of the beam, as determined by  $L_{11}$ , is  $\frac{1}{3}^\circ$ . Fig. 4 shows a photograph of the complete array.

Preliminary measurements have yielded the following results. The measured beam width is 5 milliradians in a horizontal plane and 2 milliradians in a vertical plane, in agreement with the values calculated from the local length of the lenses and accuracy of alignment. When driven with 240 A,  $0.7 \mu\text{sec}$ , pulses the peak light power output is 500 watts.

# SUMMER SCHOOL ON INFRA-RED SPECTROSCOPY

**Reported by Enid M. Baker, A.R.I.C.**  
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The Royal Institute of Chemistry Summer School in Spectroscopy in collaboration with the Society for Analytical Chemistry and the N.A.T.O. Advanced Study Institute was held at the School of Pharmacy, London, from the 6th-12th September 1964. Two courses were offered, one on infra-red the other on nuclear magnetic resonance and the total membership was over two hundred.

The Summer School opened at 9 a.m. on 7th September when Dr. F. Hartley, Dean of the School of Pharmacy, welcomed members of the School.

The infra-red course consisted of ten formal lectures, two each morning Monday to Friday inclusive, and each afternoon of the course was divided into two separate sessions, one for practical laboratory work, the other for discussions in small seminar groups on the interpretation of infra-red spectra. On Monday afternoon a special discussion was conducted by Professor Lord of Massachusetts Institute of Technology and this formed an introduction to the later seminar sessions.

The introductory lecture was given by Dr. H. W. Thompson (Oxford University). He first discussed the ranges of the electromagnetic spectrum and the units used to indicate band positions. The most important frequencies in the infra-red range lie from  $200 \text{ cm}^{-1}$  to  $4000 \text{ cm}^{-1}$ , these are the fundamental vibration frequencies. Absorption of infra-red rays of this range causes the atoms to vibrate within the molecule, a process which is also accompanied by rotation of the molecule. A non-linear molecule of  $n$  atoms has  $3n$  degrees of freedom composed of 3 rotational, 3 translational and  $3n-6$  vibrational modes, each with a characteristic fundamental band frequency. For absorption to occur as a result of a change of vibrational energy, the particular vibration must be accompanied by a

change in the dipole moment. Therefore total symmetry about a band will eliminate certain absorption bands. Molecules of hydrogen chloride, hydrogen cyanide, acetylene, ethylene, taken as examples show these different modes of vibration. However, the I.R. spectra of large molecules cannot be understood in this idealised way. Certain vibrations in molecules become localized and these give rise to characteristic frequency bands for structural diagnosis, e.g.

- (1) Those in which an H atom oscillates with respect to a much heavier atom X, e.g.  
 $\text{O-H}$   $\text{P-H}$   $\text{S-H}$   $\text{N-H}$ .
- (2) Multiple links  $\text{C}\equiv\text{C}$   $\text{C}=\text{O}$   $\text{C}=\text{N}$   $\text{C}=\text{C}$   
 $\text{S}=\text{O}$   $\text{P}=\text{O}$ .

However, limitations are imposed on these principles of structural diagnosis. Masses attached to groups affect the oscillation and cause shifts in frequency. Electronic effects of attached groups alter the force constants and therefore the frequencies. Conjugation, cumulation and ring strain alter frequencies.

The second lecture on Monday morning was given by Dr. L. J. Bellamy (Ministry of Aviation). He emphasized the need for common sense in the interpretation of bands as 80% bands in low frequency vibrations cannot be interpreted and even with the other 5-10% there is an overlap. C-H stretching frequencies can be differentiated for  $\text{CH}_3$  and  $\text{CH}_2$  using a grating. Adjacent atoms alter the frequencies. C-H bending frequencies of the  $\text{CH}_2$  scissors and  $\text{CH}_3$  asymmetric and symmetric vibrations can be identified and these are also altered by adjacent groups. Isopropyl and isobutyl groups can also be differentiated. The  $\text{CH}_2$  rocking, twisting and wagging modes and C-H stretching vibrations in aldehydes all give characteristic bands. In  $\text{X}=\text{Y}=\text{Z}$  types such as isocyan-

ates the frequency is the result of violent coupling pushing the bands apart. Nitrite groups give bands of very variable intensity from very strong to undetectable. The introduction of oxygen alters the frequency and quenches the intensity of the band.

Mr. A. R. Philpotts (Distillers Co. Ltd.) gave the first lecture on Tuesday morning on alkenes, alkynes and aromatic compounds.

The more useful group frequencies used in characterising these hydrocarbons lie in narrow well defined ranges; some may shift outside these limits under the influence of polar substituents, *e.g.* in ethylene, substituents alter the fundamental modes of vibration. Some frequencies are still characteristic of ethylene, others of the substituent and its location.

O-H stretching vibrations and carbonyl frequencies was the title of Dr. Bellamy's second lecture given on Tuesday morning.

The infra-red absorption band arising from the O-H valence vibration is one of the earliest known and studied. It is a simple method for following the phenomenon of hydrogen bonding since when this occurs the OH band length is increased and the absorption band shifts to a lower frequency. The hydroxyl group is very highly polar, and therefore associates with any other molecules having some degree of polar attraction, so that it is only in the vapour state or in dilute solution in non-polar solvents that the absorption of the free OH vibration is observed except among compounds where steric hindrance can prevent or reduce the amount of bonding. Temperature differences also alter the position of the bands. Nevertheless it is possible to differentiate between intermolecular, intramolecular and chelated bands and to decide for example whether an intermolecular association is dimeric or polymeric in type. Intermolecular bands are broken by dilution with non-polar solvents increasing the proportion of free OH whereas intramolecular bands are independent of concentration and no free OH is formed.

Frequencies of the carbonyl group in ketones, aldehydes, esters, anhydrides, acids, amides, *etc.*, can be affected by physical and chemical changes. Physical effects include mass effects, coupling, hydrogen bonding and change of bond angle. Chemical effects include (1) inductive effect, where sucking away of electrons raises the frequency, (2) resonance effects, where delocalization of electrons lowers the frequency, these two effects can occur together, (3) field effects, *e.g.* conjugation.

The first lecture on Wednesday morning was also given by Dr. Bellamy. This lecture covered:—

(1) Frequencies below 1600 cm<sup>-1</sup>. In this finger-print region the frequencies cannot all be identified.

(2) Characteristic frequencies of X=O links, *e.g.* N=O, S=O, P=O.  
N=O is like C=O and all effects which raise carbonyl frequency raise N=O frequency and all effects which lower carbonyl frequency will lower N=O frequency.

(3) Characteristic frequencies of X  $\begin{smallmatrix} =0 \\ -0 \end{smallmatrix}$  links, *e.g.* N<sub>2</sub>, S<sub>2</sub>, C<sub>2</sub><sup>-</sup>.

(4) Single Band Frequencies: Carbon Oxygen stretching vibrations in ethers. Silicon-oxygen Phosphorus-oxygen vibrations. C-Halogen frequencies. OH deformation frequencies in alcohols and acids. NH deformation frequencies in amines.

Lecture No. 6 was given by Dr. C. G. Cannon (British Nylon Spinners) on characteristic frequencies of some nitrogen compounds.

In the case of amines the second shell of electrons on the nitrogen hybridize and try to adopt a tetrahedral configuration. The NH<sub>2</sub> in a primary amine behaves as CH<sub>2</sub> and can be identified by the presence of two absorption bands in the NH stretching region arising from the symmetric and asymmetric vibrations of the hydrogen atoms.

Hydrogen bonding results in a shift towards lower frequencies but the bonds are weaker than OH groups, therefore the bands are sharper and shift is less.

Amines show no well developed system of rocking and twisting as in CH<sub>2</sub> but show a scissor deformation absorption. In aromatic amines there is interaction between the  $\pi$  orbital of the aromatic ring and the lone pair on the nitrogen to give Sp<sup>2</sup> hybridization. The electron distribution and the polarity on the N-H band is changed and frequencies go up. Wagging and rocking modes do occur but are too weak in intensity to be found.

Amines react very quickly with carbon dioxide to form carbamates in the absence of water and can crystallise out in an infra-red cell. For amino acids the hydrochloride spectra are often better for identification than the free acid. In amides the orbitals of the oxygen, carbon and nitrogen interact to give Sp<sup>2</sup> hybridisation and this factor makes amide vibrations very interesting. Electronic interaction couples the O-C-N group to give a complex sequence of bands.

Dr. Bellamy's last lecture on Thursday morning covered the origins of frequency shifts.

*XH stretching modes.* The origins of unique XH frequencies for each element and for the smaller changes which accompany a change of charge on that element. The relationship between frequency, force constant and band polarity.

*X≡Y vibrations.* The effects of changes of mass of the substituents. The effects of changes in the

strength of the band between X and the substituent chemical effects.

$C=C$  vibrations. Mass and force constant effects.

The origins of frequency change with  $C > C =$

angles. The effects of fluorine substitution.

$C=O$  vibrations. The predominance of chemical factors. Relationships with chemical properties. The special cases of anhydrides and of strained rings. Field effects.

The present theory of this lecture may be modified in time but the broad outlines are agreed.

Dr. R. L. Williams (Ministry of Aviation) then discussed the effects of the medium on I.R. spectra.

Considerable changes of both frequency and intensity occur in the I.R. spectra of molecules on going from the gaseous to the solution phase. The basis of such changes was discussed in terms of current theories *viz.* the Kirkwood-Bauer-Magat theory of dielectric constants and the specific molecular inter-action theory. Applications of solvent effects to spectral analysis were considered, including the assignment of specific vibrations, rotational isomerism, and rotation in solution. The spectra of substances held in solid matrices or adsorbed as films on surfaces were discussed as special cases of environmental effects.

Dr. G. Wilkinson (Kings College, London) gave the first lecture on Friday morning which covered the general features of low frequency I.R. spectroscopy. These included pure rotational spectra of gases, low frequency internal modes and the lattice vibrations of molecular crystals, the study of torsional modes of vibration and the determination of barriers to internal rotation, with the low frequency spectra resulting from hydrogen bonding. The complementary character of Raman spectroscopy in assigning low frequency modes of vibration was emphasized.

Professor Lord gave the final lecture and he discussed the integration of other structural methods with I.R. spectroscopy. These included Raman, NMR, mass, X-ray, emission and microwave spectroscopy.

Professor Lord also gave the introductory lecture to the afternoon seminar on Monday afternoon. He reviewed the procedures adopted in the interpretation of I.R. spectra and discussed several examples of spectra. In qualitative analyses an unknown can be identified by comparing with a known spectrum obtained under the same conditions. Group frequencies can be found empirically or from tables of group frequencies. Not all group frequencies are equally reliable, and they represent an average of many measurements and the range given does not show the distribution. Molecular symmetry may suppress a group frequency and chemical effects may suppress the intensity of a

group frequency. Group frequencies do not often apply to the first member of a series. Intensities and band widths are important adjuncts to group frequencies.

In the afternoon seminar sessions 29 spectra were interpreted under the guidance of a tutor. Members moved to different tutors and groups each day. Brief descriptions were given of each example. In some cases the substance could be identified, in others the spectrum could be identified in terms of basic structural groups.

The remainder of each afternoon was spent in laboratory sessions on the practical techniques of I.R. spectroscopy and a choice was offered between a basic or a more advanced course. Spectrometers from three different firms were provided and engineers from each firm were on hand to give any necessary assistance.

## Basic Practical Techniques

### Experiment 1. Calibration of the spectrometer

Commercial I.R. spectrometers are capable of a good wavenumber or wavelength accuracy but it is essential to know how far the indicated frequency values depart in fact from the true values. There are many reasons why a spectrometer should indicate frequency values different from the correct ones but in the main it is due to very slight imperfections in the cam controlling the littrow mirror movement, or in the various linkages controlling grating movement. Spectrometer calibration should be carried out fairly frequently and this is best accomplished by using standard substances whose spectra have been fully investigated and accurately recorded. The usual substances involved in spectrometer calibrations are polystyrene, ammonia gas, water vapour and indene. 1,2,4, trichlorbenzene is used for the range 625-400cm<sup>-1</sup>.

### Experiment 2. Cell Thickness by the Interference Fringe Method

Due to the high absorption characteristics of many organic compounds in the I.R. region, very short path length cells are employed, and to utilise the Beer-Lambert relationship, these path lengths must be determined with some accuracy. One of the best ways is by the interference fringe method. If two windows are separated by a thin film of air (or by any other material whose refractive index differs widely from that of the windows) some reflection occurs from the inner surfaces so that the two beams A (direct) and B (reflected) differ by approximately 2t in path length (Fig. 1). If 2t is an integral number of wavelengths  $\lambda$  of the incident light, then A and B reinforce each other and a high % transmission results. If 2t is

equal to  $\frac{n}{2} \lambda$  where n is odd then A and B interfere

and a low % transmission results. Thus the "spectrum" of an empty cell will be a sine curve and from the separation of the fringes, the cell thickness may be calculated.

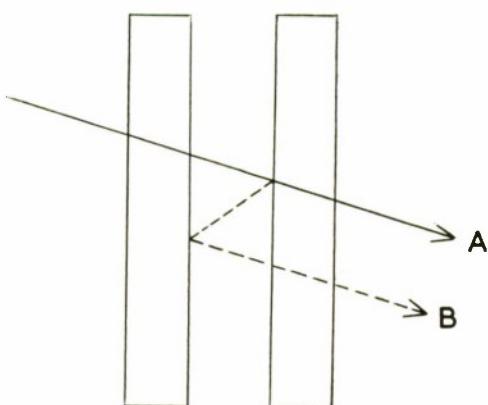


Fig. 1.

#### Instruments recording in wavelengths

$$t = \frac{\eta \lambda_1 \lambda_2}{2(\lambda_1 - \lambda_2)}$$

where

$t$  = true cell thickness in microns

$n$  = number of fringes between  $\lambda_1$  and  $\lambda_2$ , i.e. seven fringes between a and o (Fig. 2).  $\lambda_1$  and  $\lambda_2$  = wavelengths in microns between which fringes are counted.

#### Instrument recording in wavenumbers

$$t = \frac{\eta}{2(v_1 - v_2)}$$

where

$t$  = true cell thickness in cms.

$n$  = number of fringes between  $v_1$  and  $v_2$ , i.e. seven fringes between a and o above.  $v_1$  and  $v_2$

= wavenumber values between which fringes are counted.

#### Experiment 3. Simple Liquid Spectra

The spectrum of a non-volatile liquid may be scanned by a very simple "liquid sandwich" technique. In this, the liquid is trapped, as a very thin film, between rock salt plates held apart by a lead, aluminium or Teflon spacer.

#### Experiment 4. Preparation and Examination of a "Nujol Mull"

To prevent loss of radiation by scatter from the crystals of a solid placed in the beam of a spectrometer, and to offset the Christiansen effect, the interstices between crystals can be filled by some material whose refractive index is closer to that of the substance being examined than to the refractive index of air. This substance must have very few I.R. absorption peaks of its own so that it interferes as little as possible with the spectrum of the material to be examined. High boiling petroleum ("nujol" or liquid paraffin B.P.), fluorinated hydrocarbons (fluorolube), or hexachlorobutadiene have been used for several years in this connection. The latter two are of use when information is sought concerning the C-H bonds in the solid.

About 50-100 mgms of the solid to be examined are ground in an agate mortar with an agate pestle until the solid has been reduced to a very fine powder. One-two drops of Nujol are added and grinding is continued until a smooth paste results. This is transferred to a rock salt plate and squeezed out to a uniform layer with another plate. The mull sandwich is mounted in a cell holder and its spectrum run. If the mull is very absorbent the plates can be squeezed closer together to give a thinner film and the spectrum re-run. The spectrum is compared with a Nujol blank examined in the same way.

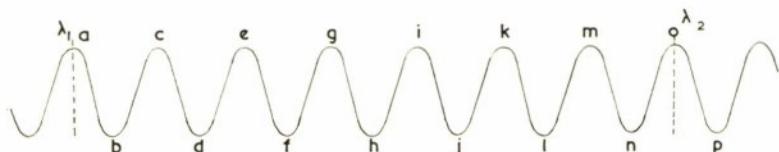
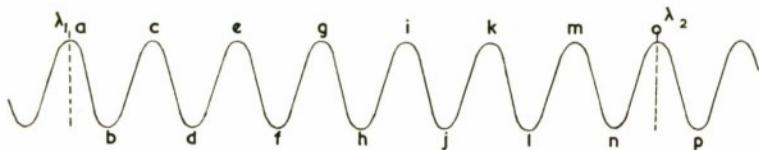


Fig. 2.



### Experiment 5. Pressed disc technique

Alkali halide salts, particularly potassium bromide and potassium chloride, can be "fused" to clear glasses at room temperature in vacuo at a pressure of 15-30 tons/sq. in. Any solid intimately mixed with the halide before pressing is held in the clear or relatively clear disc and its spectrum may be obtained since the alkali halide shows little or no absorbance over the range concerned. The literature is extensive and although an attractive method a number of difficulties may arise (see Duyckaerts, G., *Analyst*, **84** (1959), 201).

### Experiment 6. Examination of substances in solution

Solution techniques are commonly employed in I.R. spectroscopy. The main difficulty lies in the selection of the solvent. Most solvents have strong absorption characteristics in their own right and so these peaks will be superimposed upon those of the solute. Solvents most commonly employed are carbon tetrachloride, methylene chloride, and carbon disulphide but others which have been used include cyclohexane, tetrachlorethylene, acetonitrile, etc. Pure solvent is usually placed in the reference beam at a thickness sufficient to cancel out the solvent peaks in the sample. This leaves the solute peaks alone, except in those regions where the solvent absorbs so strongly that no energy remains in either beam and the pen does not receive any signal.

### Experiment 7. Quantitative Analysis—Production of Calibration Curve

Quantitative work in the infra-red, as in the visible and ultra violet portions of the spectrum, is founded upon the Beer-Lambert law which may be written

$$A = \Sigma c.l.$$

$$\text{where } A = \text{absorbance} = \log \frac{I_0}{I} = \log \frac{1}{\text{Transmission}} = \log \frac{100}{T\%}$$

$c$ =concentration

$l$ =path length

$\Sigma$ =a constant

Strictly  $\Sigma$  is only constant so long as monochromatic light is used and in practice, most infrared spectrometers give a finite band width and so the ideal conditions are not met. Generally, the consequences are not serious although the effect shows occasionally as a falling off in linearity in the calibration curve plot of  $A$  with concentration. A calibration curve of naphthalene in cyclohexane was to be prepared in this case.

### Experiment 8. Investigation of Hydrogen Bonding

The O-H stretching bands are important in the spectra of alcohols and phenols. Where hydrogen bonding can occur however the band is broad, whereas in molecules where the hydroxyl groups are "free", a sharp band results. The broader band, indicative of bonded molecules is observable about  $3400 \text{ cm}^{-1}$ , whereas the sharp band arising from "free" molecules occurs at about  $3620 \text{ cm}^{-1}$ .

In this experiment a substance exhibiting hydrogen bonding (cyclohexanol) was to be examined in solution in a non-polar solvent (carbon tetrachloride). As the solution concentration is reduced, so is the extent of bonding until in very dilute solution, no hydrogen bonding is evident. To study this effect comparatively it is advisable to maintain the number of absorbing molecules in the light path constant in each case. This can be accomplished by keeping (cell length)  $\times$  (concentration) constant.

### Advanced Course

The advanced practical course consisted of seven experiments as follows:—

#### Experiment A. To study the effect of (1) Scanning Speed and (2) Resolving Power on the Height of I.R. Absorption Peaks

There are two main reasons why a particular infra-red absorption band may show a peak height which is less than the true value:—

- (1) Because the spectrum is run too quickly for the recording system to present the information.
- (2) Because the resolution given by the monochromator is less than that required to give the true contour of the band.

In practice the first effect is easily overcome by reducing the scanning speed until no further improvement in peak height is obtained. The second is less easy to deal with for narrow absorption bands. With grating spectrometers under the appropriate scanning conditions peak heights can be obtained in most cases which are a good approximation to the true bands. This point can be checked by recording the spectra at different slit widths and noting the change in peak heights. It is of course necessary to ensure that errors from too fast scanning are not being incurred. One can also record the same bands using a prism monochromator and note the much lower peak heights that are obtained. These points were demonstrated using cyclohexane and a prism grating double monochromator.

#### Experiment B. To prepare and use a K Br disc using a microframe

Using the conventional technique with a circular K Br disc the bulk of the sample is not in the

light beam. Considerably smaller samples may be used if the area of the disc is reduced so that it coincides approximately with the cross section of the light beam. To avoid the necessity for a special die, the mixed K Br and sample may be confined to a suitable small area by means of a cardboard microframe inside a normal 13 mm die. This experiment was carried out using cholesterol as a sample.

*Experiment C. To study the effect of solvents on the positions of some I.R. bands.*

The exact positions of many infra-red absorption bands vary with the solvents used. As well as finding large shifts with solvents that interact strongly with the solutes, for example with hydrogen bonding solvents, smaller but still appreciable solvent shifts may be encountered with other solvents that might otherwise be regarded as inert. This was demonstrated by measuring the positions of the C=O and C=C bands of mesityl oxide in six different solvents.

*Experiment D. Multicomponent mixture analysis*

If the components present in the mixture possess unique absorption frequencies then the mixture may be analysed quantitatively merely by application of simple calibration curves. Whilst this state of affairs is possible for two or even three components without interference it is unlikely to exist for more than three. In this case two interfering components will be considered.

Since  $A_{\text{mixture}} = A_1 + A_2$

and  $A = (\text{const.}) \times c \times l$

where  $c$  = concentration in suitable units

$l$  = pathlength

Then  $A_{\text{mixture}} = k_1 c_1 l + k_2 c_2 l$

$$= l(k_1 c_1 + k_2 c_2)$$

By taking measurements at two independent wavelength values, at each of which  $k_1$  and  $k_2$  are known, two simultaneous equations may be obtained which can be solved for  $c_1$  and  $c_2$ . In the case of (n) components, measurement is made at (n) wavenumber values giving (n) simultaneous equations. These are usually solved by a matrix inversion method.

*Experiment E. Attenuated Total Reflectance (A.T.R.)*

This technique was developed by Fahrenfort (1961) and involves the total reflectance of an infrared beam of radiation from the back face of a prism, during which process a little of the beam energy "escapes" from the prism and is then returned into the prism. During its passage outside the prism, this portion of the beam may traverse

a sample in close contact with the prism and so become selectively absorbed much as in a transmission spectrum. Examination of the beam energy after traversing the prism and sample yields a spectrum similar in a great number of respects to the transmission spectrum. This technique lends itself particularly to the examination of coatings (e.g. on paper, or wood) or samples difficult to handle (e.g. toothpaste or soap) or aqueous solutions, etc. The prisms used must be of a high refractive index relative to air and the usual material involved are:—

AgCl—refractive index 2.0 at 2000  $\text{cm}^{-1}$ .

KRS-5—refractive index 2.38 at 2000  $\text{cm}^{-1}$ .  
(thallium bromide iodide)

The use of KRS-5 is normal in this country. It provides good results but acquires a "bloom" and periodically needs to be lapped using optical rouge otherwise contaminants remain on the surface and interfere with subsequent spectra. KRS-5 is semi-hard but bruises easily so must be handled with care.

A coated paper and aqueous solutions of sodium nitrate were examined by this technique.

*Experiment F. Dispersion of solids for infra-red analysis.*

Spectra obtained from solutions are most suitable for quantitative and qualitative studies but there are very few solvents which do not absorb strongly in the 650-200  $\text{cm}^{-1}$  region. Carbon disulphide and carbon tetrachloride are transparent over extended regions but no others are as good. Thus, whilst investigation of substances soluble in these solvents has been simple, investigation of substances insoluble in these and other similar solvents has been dependent on the use of solid films, mulls and discs as the only available methods of obtaining spectra.

Spectra can be obtained however from solids if the particle diameter is considerably less than the wavelength of radiation used, and if a uniform, stable fluid suspension of particles, less than  $3\mu$  in diameter, could be prepared, this suspension would serve as well as a solution above  $7\mu$  (below 1400  $\text{cm}^{-1}$ ). It has been found\* that solids may be dispersed in solvents such as carbon disulphide and carbon tetrachloride in the presence of aluminium stearate which in some cases appears to act as a solubilising as well as dispersing agent.

To prepare the emulsion 250 mgm of the solid for analysis, with 250 mgm aluminium stearate is placed in a stoppered flask with 25 ml. of carbon disulphide and the mixture raised to boiling on a water bath. After quickly cooling, 50 ml. of 3 mm.

\*Dolinsky. *J. Assoc. Offic. Agric. Chem.*, 34 (1951) 748.

glass beads are added and the stoppered flask shaken vigorously for 20-60 minutes on an automatic shaker. The resulting suspension is viscous but fluid enough to be injected via a hypodermic syringe into a standard cell.

A 1% solution of aluminium stearate in  $\text{CS}_2$  was prepared and used as a "solvent".

Suspensions are usually stable for 30 minutes at least. On long standing a solid may settle out but can be re-dispersed on shaking by hand. Spectra of p. toluene sulphonamide, sucrose and isatin were obtained by this method.

#### Experiment G. Use of scale expansion

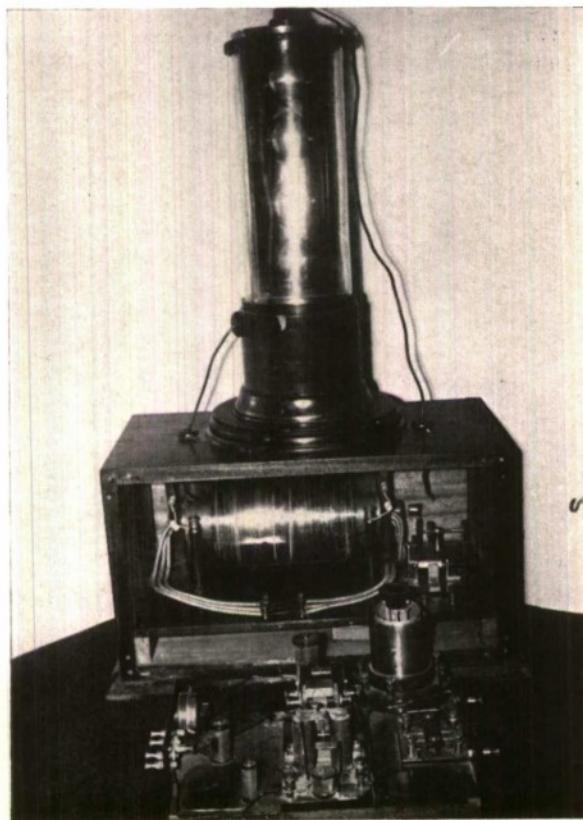
Very small quantities of material often have to be examined by infra-red spectroscopy. The spectrometer can detect the small transmission differences obtained in the spectra, but the records cannot display them in an easily recognisable way. To overcome this the transmission scale can be

expanded so that a weak spectrum will cover much more of a full recorder range. An expanded spectrum is not identical with a normal strong spectrum although the essential similarities are well shown up. The former is expanded linearly on a transmission scale ( $T$ ), while the latter increases with the concentration or, ideally,  $\log \frac{1}{T}$ .

An expanded spectrum looks distorted and "pulled out" when compared with a normal spectrum. The use of scale expansion was demonstrated with weak solutions of o-cresol in cyclohexane.

This experiment concluded the advanced practical course.

During this busy and excellently organised week the social side was not forgotten. A buffet supper and social evening was held on the Tuesday evening and the Summer School Dinner at the Connaught Rooms brought the School to a close on the Friday evening.



#### THE FIRST NAVAL TRANSMITTER

*The full scale working replica of the first Naval transmitter, designed and constructed in H.M.S. Defiance by Captain H. B. Jackson, R.N., in 1897. Range 5,800 yards, speed 8 w.p.m.*

# DESIGN AND SYNTHESIS OF A VALVE CONTROLLED ELECTRO-HYDRAULIC SERVO SYSTEM

By Peter Smith and C. W. Dent, D.C.Ae., G.I.Mech.E.  
*Admiralty Underwater Weapons Establishment*

The authors have often been asked by project designers how they can adapt their knowledge of practical sciences, *i.e.*, Mechanics of Fluid, Electronics and Mathematics to the modern high response electro-hydraulic servo systems of to-day. Perhaps because such a question cannot be answered in a few minutes some of the questioners have been disappointed. This article is written to allay disappointment and dispel the cloud of mystery surrounding such a combination of disciplines that electro hydraulics demands.

## Why Electro Hydraulics ?

Fluid power can be enormously powerful and compact. It forms the muscles of a system but suffers a disadvantage when controlled mechan-

ally, of lost motion and poor high frequency response, particularly if the controlling source is far removed from the hydraulics.

Conversely, electrical power when applied in moving loads becomes very cumbersome, an example being the tractive electro magnet, where the forces obtained are at least ten times smaller than for a comparable hydraulic machine for the same power input. Another example is the small electric motor which, in order to supply any appreciable torque, has its output shaft rotating at high speed. To allow a motor to drive a load it must be geared down and therefore a gear reduction becomes a necessity where backlash in the gears and their bulk preclude them from accurate high response systems.

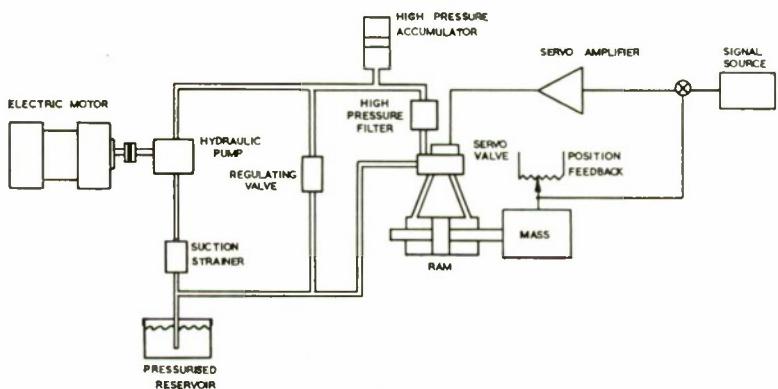


Fig. 1.

*A typical valve controlled, constant pressure, electro hydraulic system.*

## A High Response Valve Controlled System

The valve controlled system is the only practicable way at present of employing hydraulic power for high response systems, Fig. 1 showing a typical circuit.

Fluid is drawn from a reservoir via a suction strainer to a pump where the fluid is compressed and therefore pressurised and put to a servo valve controlling a double acting hydraulic ram moving the load. A high pressure filter mounted in the high pressure line as close to the servo valve as possible protects the valve from damaging contamination. A regulating valve shunted across the pressure and return lines keeps the system at constant pressure. Often an accumulator fitted to the high pressure line helps to damp out unwanted pressure pulses in the system and also supplies fluid to the system when the pump capacity is exceeded.

The controlling circuit consists of an electronic signal generator feeding a servo amplifier controlling the first stage of the electro hydraulic servo valve. Because hydraulic orifices are difficult to manufacture with exactly the same dimensions the valve gives a small unbalance of fluid power to the double acting ram resulting in a gradual drift toward one side of the actuator. Consequently a voltage signal from a position feedback is fed back to the input of the amplifier, electrically subtracted from the input signal to return the ram to its hydraulic centre.

Similar conditions of fluid unbalance occur in the actuator assembly containing the ram where the effect of different leakage rates from each end of the ram would also cause a gradual drift even with the servo valve exactly balanced. This effect is also quite significant and can still occur under certain conditions even with feedback if the resolution in the ram-load combination is superior to that of the valve-feedback combination.

Suppose as an example of electro-hydraulic design a specification is submitted stating that a

TABLE 1

Frequency c.p.s.	Amplitude ins. (centre to peak)
30	.058
40	.0345
50	.022
60	.0155
80	.0084
100	.0055
150	.0025
200	.0014

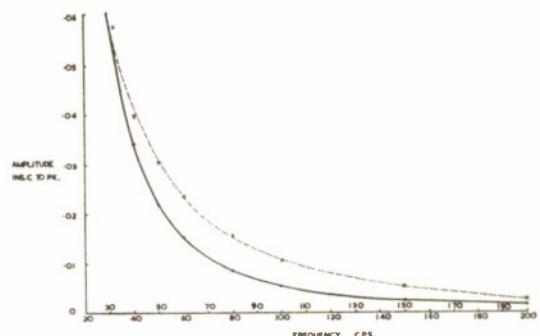


Fig. 2. Graph of amplitude-frequency data given in Table I, shewn by full line. Broken line shows results of Table III, Appendix (ii).

load of 200 lbs. weight is to be reciprocated over a frequency range of 30-200 c.p.s. to the following frequency-amplitude data given in Table 1.

Table 1, also shown graphically in Fig. 2, is a good example of a high response vibrator its uses being a machine to simulate dynamic performance which missile and aircraft components have to withstand or to drive the road wheels of a car or lorry in the laboratory to gain information on the dynamic loading of the above mentioned road wheels.

It is suggested that the applications mentioned above are typical but not necessarily suitable since the above specification does not conform to D.E.F. 133 for missile testing nor road wheel testing where the weight of the car, forming a static load, consumes a significant proportion of the rated thrust.

### The Ram Area

The guiding rule in this design example is to obtain a ram area consistent with a high natural frequency above the highest working frequency which in this example is 200 c.p.s.

Knowing the actual ram movement to be  $\pm 0.058$  in. maximum, then in order to allow the ram to work about its hydraulic centre and prevent it hitting the end stops should an occasion arise where the ram is not centred correctly, let the total permissible ram movement be set at  $\pm 0.25$  in. then:

$$\text{Ram movement} = \pm 0.25 \text{ in. maximum}$$

$$\text{Ram area} = A \text{ sq. in.}$$

$$\text{Volume swept out by the ram} = A \times \pm 0.25 \text{ in.} = \frac{A}{2} \text{ cubic in.}$$

Note here that when designing the actuator the swept volume should include any oil way volume between the ram and valve, the latter being assumed closed in the centre position.

$$\text{and Effective mass} = \frac{200}{32.2 \times 12} = 0.52 \frac{\text{lbs. sec.}^2}{\text{inch}}$$

Assuming the use of a commercial hydraulic fluid having a bulk modulus of  $2 \times 10^5$  lbs./sq. ins. (i.e. Specification D.T.D. 585) then the hydraulic stiffness, considering two chambers in the case of the double acting ram will be:

$$\begin{aligned} \text{Hydraulic stiffness} &= 2 \times (\text{Ram Area})^2 \times \text{Bulk Modulus} \\ &= \frac{2 \times A^2 \times 2 \times 10^5}{\text{Swept Volume}} \\ &= \frac{2 \times A^2 \times 2 \times 10^5}{\frac{A}{2} \times \frac{1}{2}} \end{aligned}$$

$$\text{Therefore Hydraulic Stiffness} = 16 \times 10^5 A \text{ lbs./in.}$$

Assuming a natural frequency for the ram to be 300 c.p.s.

$$\begin{aligned} \text{then } 300 &= \frac{1}{2\pi} \sqrt{\frac{\text{Stiffness}}{\text{Mass}}} \\ \text{i.e. } 300 &= \frac{1}{2\pi} \sqrt{\frac{16 \times 10^5 A}{0.52}} \end{aligned}$$

$$\text{Therefore the ram area (A)} = 1.14 \text{ sq. in.}$$

#### Peak Acceleration, Velocity and Thrust

Since the specification lists discrete frequencies with specific amplitudes the movement of the load at any frequency is sinusoidal which allows the acceleration and velocity calculations to be easily computed.\*

$$\text{i.e. Peak Acceleration} = (2\pi \times f)^2 \times \text{amplitude} \text{ (c. to pk)}$$

Taking an example. At 200 c.p.s. the Acceleration =  $(2\pi \times 200)^2 \times 0.0014$

$$\text{Therefore Acceleration} = 2,220 \text{ ins./sec.}^2$$

This peak acceleration is a constant value at any frequency and amplitude listed in Table 1. Often the peak acceleration is spoken of in terms of 'g' loading. In this example the 'g' loading is

$$\frac{2220}{12 \times 32.2} = 5.7; 6g \text{ say.}$$

The peak velocity unlike the peak acceleration changes with each frequency listed in Table 1.

$$\begin{aligned} \text{Peak velocity} &= 2\pi f \times \text{amplitude (c. to pk)} \\ \text{e.g. At 30 c.p.s. the pk velocity} &= 2\pi \times 30 \times 0.058 \\ &= 11.4 \text{ in./sec.} \end{aligned}$$

Knowing the mass and acceleration the peak thrust is found using Newton's second law.

$$\text{Force} = \text{Mass} \times \text{Acceleration.}$$

\* Even if the specification listed a complex wave form, application of the Fourier analysis (which states that a complex wave form consists of any number of sinusoids with phase difference), will break the problem down to discrete frequency-amplitude measurements.

$$\begin{aligned} \text{In this example Pk Thrust} &= \frac{200}{32.2 \times 12} \times 2220 \\ &= 1140 \text{ lbs.} \end{aligned}$$

#### Peak Flow

The system must be capable of delivering the peak thrust quoted above which lead to horse power considerations via the flow requirement, the latter being the product of the ram area and the velocity. Thus the peak flow requirement will be:

$$\begin{aligned} \text{Peak flow} &= 1.14 \times 11.4 \\ &= 13.0 \text{ cubic in./sec.} \end{aligned}$$

#### System Pressure and H.P.

The selection of a system pressure is often influenced by the type of pumps available which can cope with the flow and thrust required by the system. With the calculated ram area, a system pressure of 1500 lbs. sq. in. will suffice; to set the system pressure unnecessarily high would only waste horse power since:

$$\begin{aligned} \text{Theoretical h.p.} &= \frac{\text{Pressure} \times \text{flow}}{550 \times 12} \\ &= \frac{1500 \times 13.0}{6600} \end{aligned}$$

$$\text{Therefore Theoretical h.p.} = 2.95$$

Assuming an overall efficiency of 80% for the electric motor and hydraulic pump the required horse power will increase to 3.7 plus the power loss due to leakage.

#### Hydraulic Leakage Losses

Fig. 3 shows a high response servo valve employing two stages of hydraulic amplification controlling a double acting ram attached to the load. Because controlled leakage is necessary in the first stage for stability reasons and mechanical clearances are needed in the second stage to allow the spool to move relative to the sleeve, the leakage rates need calculating in order to allow for the additional H.P. that leakage necessarily incurs.

#### First Stage

Leakage flow through inlet orifices (see Fig. 3).

$$Q_1^2 = \frac{(P_1 - P_2)d^4}{1.09 \times 10^{-4}}$$

Assuming an orifice co-efficient of 0.8, then

$$P_1 - P_2 = 1,300 \text{ lbs./ins.}^2$$

Now  $d = 0.0064$  ins., where  $d$  is the orifice diameter.

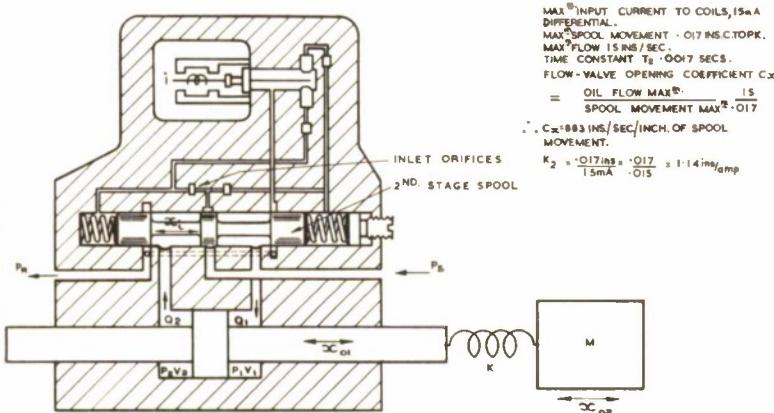


Fig. 3.

Servo valve data.

N.B. THE TERM  $\Delta C$  APPEARS ONLY IN APPENDIX (i) AND THE CONCLUSION

Hence  $Q_1 = 0.14$  cubic ins./sec., the flow through one orifice.

and  $2Q_1 = 0.28$  cubic ins./sec., the flow through two orifices.

### Second Stage

Leakage end flow of second stage spool to return (see Fig. 3).

$$P_1 - P_2 = 1,500 - 1,300 = 200 \text{ lbs. sq. ins.}$$

$$\frac{\pi D b^3 (P_1 - P_2)}{12 \mu L}$$

where  $Q$  = flow cubic ins./sec.

$D$  = Diameter of spool (in.)

$b$  = Radial clearance between spool and sleeve.

$P_1 - P_2$  = Pressure drop.

$$\mu = \text{Viscosity of fluid } 1.1 \times 10^{-6} \frac{\text{lbs. sec.}}{\text{ins.}^2}$$

for DTD 585

$L$  = Length of spool land (in.)

$$\text{Therefore } Q = \frac{\pi \times 197 \times 0.0001^3 \times 200}{12 \times 1.1 \times 10^{-6} \times 10}$$

$$\text{Hence } Q_2 = 0.00009376 \text{ cubic ins./sec.}$$

$$\text{and } 2Q_2 \approx 0.0002 \text{ cubic ins./sec.}$$

Leakage from pressure inlet to return via second stage spool.

$$\text{Here } P_1 - P_2 = \text{Supply Pressure} = 750 \text{ lbs. sq. in.}$$

2  
(2 orifices in series)

$d = 0.0097$  ins. and is the equivalent diameter to correspond with actual spool clearance. Spool diameter  $0.196$  ins.; clearance  $\frac{0.00010}{0.00012}$  ins.

Assuming no underlap:

$$\frac{Q^2}{3} = \frac{(P_1 - P_2)d^4}{1.09 \times 10^{-4}}$$

$$\therefore Q_3 = 0.26 \text{ cubic ins.}$$

$$\text{and } 2Q_3 = 0.52 \text{ cubic ins.}$$

$$\text{Thus the servo valve leakage} = 2(Q_1 + Q_2 + Q_3) \\ = 0.809 \text{ cubic ins./sec.}$$

### Ram Leakage

$$D = 2.00 \text{ in. } L = 1.0 \text{ in. (See Fig. 3)}$$

$$\text{Clearance on diameter} = 0.0004 \text{ ins.} = 2b$$

$$\text{Pressure Drop} = 750 \text{ lbs. sq. ins.} (P_1 - P_2)$$

$$\text{Viscosity of DTD 585 hydraulic fluid at } 60^\circ\text{C} \\ = 1.1 \times 10^{-6} \frac{\text{lbs. sec.}}{\text{sq. ins.}} \text{ (Reyns)}$$

$$\text{Flow, cubic in./sec. (Q)} = \frac{\pi D b^3 (P_1 - P_2)}{12 \mu L}$$

$$\text{Therefore leakage flow} = 0.00286 \text{ cubic in./sec.}$$

Since there are two similar leakage paths

$$\text{Ram leakage} = 0.0057 \text{ cubic in./sec.}$$

The total leakage of servo valve and ram  $\approx 0.806$  cubic ins./sec. which represents 5.3% of the rated flow of a 15 cubic ins./sec. valve and is equivalent to a power loss of 0.15 H.P. raising the H.P. requirement to 3.85.

A summary of the design data is given in Table II.

Given the compiled data in Table II the hydraulics can be designed with the exception of the accumulator. As previously mentioned one of the functions of the accumulator is to supply oil at peak demands when the flow demanded by the ram exceeds the pump capacity; how often this happens with respect to time is known as the "duty cycle". To illustrate the significance of the duty cycle:

Table II

Frequency cps	W. rads/sec.	Amplitude ins.	Pk. Accn. ins./sec <sup>2</sup>	Pk. Vel. ins./sec.	Flow cu. ins. /sec.
30	188	0.058		11.4	13.0
40	251	0.0345	Constant	8.66	9.88
50	314	0.022	at	6.90	7.86
60	377	0.0155	2200	5.84	6.65
80	502	0.0084	ins./sec. <sup>2</sup>	4.22	4.80
100	628	0.0055		3.45	3.94
150	941	0.0025		2.35	2.68
200	1256	0.0014		1.76	2.02

Peak thrust  
h.p. requirements      1,140 lbs.  
                                    3.85

System Pressure  
Ram Area  
Flow      1,500 lbs. sq. ins.  
                            1.14 sq. ins.  
                            13.0 cu. ins./sec.

In Table II the maximum flow demand is 13.0 cubic in./sec. and say that the system must run in 10 minute periods, further that the pump capacity is limited to 11 cubic in./sec. then the accumulator must supply  $13.0 - 11.0 = 2.0$  cubic in./sec.

Assuming that over the 10 minute cycle, one minute will demand peak flow then oil volume lost from the accumulator to maintain system pressure will be  $2.0 \times 60 = 120$  cubic in. Therefore the duty cycle for the accumulator will be 120 cubic in./10 mins.

### Servo amplifier

The design of the servo amplifier will not be considered in this example; its characteristics however must be defined in terms of gain and phase. A good amplifier response is shown in Fig. 4 where over the 30-200 c.p.s. bandwidth there is no phase change, hence the amplifier is not frequency dependent and therefore may be mathematically defined as a constant, e.g.  $K = 15$  amps/volt input.

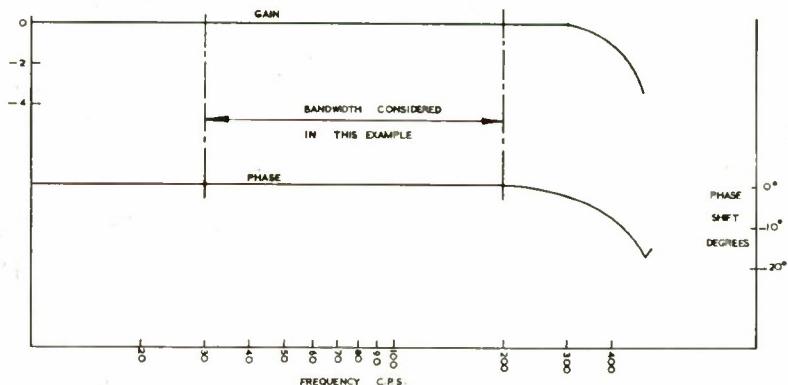


Fig. 4. Servo amplifier response. Constant gain  $K_1 = 15$  amps/volt.  
Current output from amplifier 15mA differential.  
Voltage input to amplifier  $\pm 1mV$ .

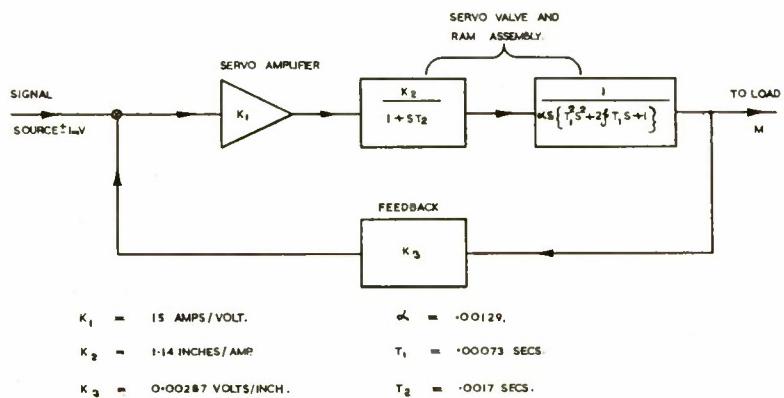


Fig. 5. Transfer functions of system components.

### System Frequency Response

The theoretical analysis chosen to determine the transfer function of the complete system is given in Reference<sup>(1)</sup>. This elegant mathematical solution is contained in Appendix (i) where Equations 24 to 28 inclusive are necessary to determine the performance of the system.

$$q_1 = C_x x_i - C_p p_1 = \frac{V}{2N} \frac{dp_1}{dt} + \frac{A}{dt} dx_{01} + q_3 \dots (24)$$

$$q_2 = C_x x_i + C_p p_2 = -\frac{V}{2N} \frac{dp_2}{dt} + \frac{A}{dt} dx_{01} + q_3 \dots (25)$$

$$q_3 = C_d(p_1 - p_2) \dots (26)$$

$$F = A(p_1 - p_2) = K(x_{01} - x_{02}) \dots (27)$$

$$= M \frac{d^2 x_{02}}{dt^2} \dots (28)$$

### List of Symbols

$Q_1$	Flow to one side of ram.
$Q_2$	Flow to other side of ram.
$q_1$	Small change in $Q_1$ .
$q_2$	Small change in $Q_2$ .
$Q_3$	Leakage or bleed flow.
$q_3$	Small change in $Q_3$ .
$P_s$	Supply pressure 1,500 lbs. sq. in.
$P_r$	Reservoir pressure.
$P_1$	Pressure to one side of ram.
$P_2$	Pressure to other side of ram.
$p_1$	Small change in $P_1$ .
$p_2$	Small change in $P_2$ .
$V_1$	Volume on one side of ram.
$V_2$	Volume on other side of ram.
$V$	Total volume in ram chamber $= V_1 + V_2 (0.584 \text{ cu. ins.})$
$X_i$	Movement of second stage spool, 0.017 in. for rated current input.
$x_i$	Small change in $X_i$ .
$X_{01}$	Movement of ram.
$x_{01}$	Small change in $X_{01}$ .
$X_{02}$	Movement of mass $M$ .
$x_{02}$	Small change in $X_{02}$ .
$K$	Ram and linkage stiffness $1.82 \times 10^6$ lbs./in.
$M$	Effective mass 0.52 lbs. sec. <sup>2</sup> /inch.
$N$	Bulk modulus of fluid $2 \times 10^5$ lbs. sq. in.
$P$	Density of fluid 0.8.
$A$	Area of ram 1.14 sq. in.
$C_x$	Flow valve opening co-efficient 883 cubic in./sec./inch of spool movement.
$C_p$	Flow-pressure co-efficient of valve $\div 10^{-6}$ about centre.
$C_d$	Flow-pressure co-efficient of bleed hole $3.4 \times 10^{-3}$ .
$a_d$	Area of leakage path.
$T_1$	Time constant of ram mass system $0.73 \times 10^{-3}$ secs.

$T_2$  Time constant of servo valve 0.0017 secs.

$K_1$  Gain constant of servo amplifier

15 amps./volt.

$K_2$  Gain constant of servo valve 1.14 ins./amp

$i$  Input signal to servo valve.

### Derivation of Transfer function from the Performance Equations

From equations 27 and 28

$$K(x_{01} - x_{02}) = M \ddot{x}_{02} \text{ where } \ddot{x}_{02} = \frac{d^2 x_{02}}{dt^2}$$

$$x_{01} - x_{02} = \frac{M}{K} \ddot{x}_{02}$$

$$x_{01} = \frac{M}{K} \ddot{x}_{02} + x_{02} \dots (29)$$

From equations 24, 25, and 26

$$q_1 + q_2 = 2C_x x_i - C_p(p_1 - p_2) = \frac{V}{2N} \left\{ \frac{dp_1}{dt} - \frac{dp_2}{dt} \right\} + 2C_d(p_1 - p_2) \dots (30)$$

From 28

$$p_1 - p_2 = \frac{M}{A} \frac{d^2 x_{02}}{dt^2} \dots (31)$$

Substitute 31 in 30 and write  $\dot{p}_1$  for  $\frac{dp_1}{dt}$  etc.

$$q_1 + q_2 = 2C_x x_i - C_p \frac{M}{A} \ddot{x}_{02} = 2A \ddot{x}_{01} + \frac{V}{2N} \frac{M}{A} \ddot{x}_{02} + 2C_d \frac{M}{A} \ddot{x}_{02}$$

$$\text{hence } 2C_x x_i = 2A \ddot{x}_{01} + \frac{VM}{2NA} \ddot{x}_{02} + (C_p + 2C_d) \frac{M}{A} \ddot{x}_{02} \dots (32)$$

Substituting 29 in 32 to bring all quantities to  $x_{02}$  re-arranging and putting  $S = \frac{d}{dt}$

$$2C_x x_i = x_{02} \left\{ S^3 \left[ \frac{2AM}{K} + \frac{VM}{2NA} \right] + S^2 \left[ C_p + 2C_d \right] \frac{M}{A} + S2A \right\}$$

hence  $\frac{\text{Output } x_{02}}{\text{Input } x_i} =$

$$\frac{2C_x}{S^3 \left[ \frac{2AM}{K} + \frac{VM}{2NA} \right] + S^2 \left[ C_p + 2C_d \right] \frac{M}{A} + S2A}$$

$\uparrow$  Ram Stiffness    $\uparrow$  Oil Compressibility    $\uparrow$  Flow Losses    $\uparrow$  Velocity term  
 $\uparrow$     $\uparrow$     $\uparrow$     $\uparrow$   
 $\dots (33)$

The above co-efficients may be found the exception being  $C_d$ . The best method of determining  $C_d$  is by selecting the required system damping ratio and evaluating as explained below.

Equation 33 may be re-written as follows:

$$\frac{x_{02}}{xi} = \frac{1}{\frac{A}{C_x} S \left\{ \left( \frac{M}{K} + \frac{VM}{4NA^2} \right) S^2 + (C_p + 2C_d) \frac{M}{2A^2} S + 1 \right\}} \quad \dots (34)$$

Introducing the appropriate co-efficients

$$\frac{x_{02}}{xi} = \frac{1}{\frac{1.14}{883} S \left\{ \left( \frac{0.52}{1.82 \times 10^6} + \frac{0.584 \times 0.52}{4 \times 2 \times 10^5 \times 1.14^2} \right) S^2 + (10^{-6} + 2C_d) \frac{0.52}{2 \times 1.14^2} S + 1 \right\}} \quad \dots (35)$$

Therefore  $\frac{x_{02}}{xi} =$

$$\frac{1}{0.00129 S \left( (0.576 \times 10^{-6}) S^2 + (10^{-6} + 2C_d) 0.20 S + 1 \right)}$$

Equation 35 may now be directly compared with the standard form

$$\frac{1}{\alpha S \left\{ \frac{S^2}{\omega_n^2} + \frac{2}{\omega_n} \zeta S + 1 \right\}} \text{ where } \alpha = \frac{A}{C_x}$$

And putting the time constant  $T_1 = \frac{1}{\omega_n}$  then

$$\frac{x_{02}}{xi} = \frac{1}{\alpha S \left( T_1^2 S^2 + 2\zeta T_1 S + 1 \right)} \quad \dots (36)$$

by direct comparison from equation 35.

$$T_1 = 0.76 \times 10^{-3} \text{ secs.} \quad \therefore T_1 = \sqrt{0.576 \times 10^{-6}}$$

$$\text{also } 2\zeta T_1 = 0.20(10^{-6} + 2C_d)$$

Selecting a damping ratio is not difficult with actuators placing reliance on mechanical seals *i.e.* closely mating parts of 0.0002 in. radial clearance, say. The clearance annulus formed by the mating parts is sufficient to increase the damping ratio to 0.8–1.0. Thus no artificial damping in the form of bleed orifices shunted across the control ports is required.

Choosing a damping ratio of 0.8 and knowing

$$2\zeta T_1 = 0.20(10^{-6} + 2C_d)$$

$$\text{then } C_d = 0.003$$

Another method of calculating  $C_d$  is as follows. Let the leakage path area be  $a_d$  then

$$C_d = \frac{110 a_d}{2 \sqrt{p_1 - p_2}}$$

and since about the zero position of the spool  $p_1 - p_2$  is small, 100 lbs. sq. ins. say

$$C_d = \frac{110 \times (1.20002^2 - 1.20^2)}{2 \sqrt{100}}$$

then  $C_d = 0.0026$  a value which agrees fairly well with the preceding method.

Continuing with the system equations determining transfer functions, system stability and frequency response then from Equation 34 the ratio,

$$\frac{x_{02}}{xi} = \frac{\text{Movement of the load mass } M}{\text{Movement of the second stage spool}}$$

$$= \frac{1}{\frac{A}{C_x} S \left\{ \left( \frac{M}{K} + \frac{VM}{2NA^2} \right) S^2 + (C_p + 2C_d) \frac{M}{2A^2} S + 1 \right\}} \\ = \frac{1}{\alpha S \left( T_1^2 S^2 + 2\zeta T_1 S + 1 \right)}$$

$$\text{Also } \frac{xi}{i} = \frac{\text{Movement of second stage pool}}{\text{Input current to servo valve}} = \frac{K_2}{1 + T_2 S}$$

$$\text{In the steady state } K_2 = \frac{0.017 \text{ in.}}{0.015 \text{ amps.}}$$

$$\text{Therefore } K_2 = 1.14 \text{ in./amp.}$$

Information for determining  $K_2$  is published by the servo valve manufacturer see Fig. 3.

Continuing with the transfer functions

$$\frac{i}{v} = \frac{\text{Differential Current into Servo Valve Coils}}{\text{Voltage Input to Servo Amplifier}} \\ = 15 \frac{\text{amps}}{\text{volts}}$$

## Determination of Frequency Response from Derived Transfer Functions

$$\text{Let } \frac{i}{v} = K_1 = 15 \text{ amps./volt}$$

$$\frac{x_i}{i} = \frac{K_2}{1+T_2S} = \frac{1.14}{1+0.0017S}$$

$$\frac{x_{02}}{x_i} =$$

$$\frac{A}{C_x} S \left( \left( \frac{M}{K} + \frac{VM}{4NA^2} \right) S^2 + (C_p + 2C_d) \frac{M}{2A^2} S + 1 \right)$$

The equations in this section are solved by putting  $S=j\omega$  and rationalising, the results being given in Appendix (ii), Tables 1, 2, 3 and 4. In Tables 1 to 3 inclusive no steady state terms are considered, i.e.  $K_1$  and  $K_2$ . In Table 4 they are included and from Table 4 the open loop frequency response is obtained. Additionally the output movement of mass  $M$  is in excess of that required since;

the overall gain from amplifier input to mass movement at 30 c.p.s. is

$$\frac{i}{v} \times \frac{x_i}{i} \times \frac{x_{02}}{x_i} = \frac{K_1 K_2}{aS(1+T_2S)} \frac{1}{\{T_1^2 S^2 + 2\zeta T_1 S + 1\}} \\ = 15 \times 1.14 \times 4.08 \quad \dots (37)$$

$$\frac{\text{Mass movement } x_{02}}{\text{Amplifier input } \frac{x_i}{i}} = 70 \frac{\text{in.}}{\text{volt}}$$

Now the full input signal to the servo amplifier is  $\pm 1\text{mV}$  thus the resulting mass movement is  $\pm 0.07 \text{ ins.}$  The required movement is  $0.058 \text{ ins.}$  at 30 c.p.s. thus an allowance is made where some forward loop gain can be sacrificed to feedback.

If Table 2 of Appendix (ii) is studied it is apparent that as  $w \rightarrow 0$  the output  $x_{02} \rightarrow \infty$ . This is due to the servo valve and ram combination integrating any non-linearities which will cause the ram to drift to one end of its stroke. To eliminate this effect a low gain position feedback is introduced, which allows a small amount of negative feedback holding the ram and mass in the central position under zero signal conditions but not adversely affecting the frequency response by any significant amount.

Defining the feedback as  $K_3$  volts/inch containing no frequency dependent term

$$\frac{\text{Output voltage } v_o}{\text{Input voltage } v_i} =$$

$$\frac{K_1 K_2 K_3}{\frac{A}{C_x} S \left\{ \left( \frac{M}{K} + \frac{VM}{4NA^2} \right) S^2 + (C_p + 2C_d) \frac{M}{2A^2} S + 1 \right\} \left\{ 1 + T_2 S \right\}} \quad \dots (38)$$

### System Stability

The stability of the system defined in the above equation can be checked by expanding the denominator and applying Routh's stability criterion.

$$\begin{aligned} & \left[ \frac{MAT_2}{KC_x} + \frac{VMT_2}{4NAC_x} \right] S^4 + \left[ \frac{MA}{KC_x} + \frac{VM}{4NAC_x} \right. \\ & \quad \left. + (C_p + 2C_d) \frac{MT_2}{2AC_x} \right] S^3 \\ & + \left[ (C_p + 2C_d) \frac{M}{2AC_x} + \frac{AT_2}{C_x} \right] S^2 + \frac{AS}{C_x} + 0 \end{aligned}$$

Thus,

$$\begin{array}{ccccccccc} a_0 & & & & a_1 & & & & \\ (1.39 \times 10^{-12} \text{ sec.}^4) S^4 & + & (2.67 \times 10^{-8} \text{ sec.}^3) S^3 & & & & & & \\ a_0 & & a_2 & & a_1 & & a_4 & & \\ a_1 & & a_3 & & & & & & \\ b_1 & & & & & & & & \\ & & a_2 & & a_3 & & a_4 & & \\ & & + (3.83 \times 10^{-6} \text{ sec.}^2) S^2 & + (1.29 \times 10^{-3} \text{ sec.}) S & + 0 & & & & \end{array}$$

$$\text{where } b_1 = \frac{a_1 a_2 - a_0 a_3}{a_1} = +3.82 \times 10^{-6}$$

Since  $b_1$  is positive and no sign change occurs in the left hand column of the array this signifies open loop stability. This is also the stage to judge the effect on system stability of varying design parameters, if required.

### Closed Loop Performance

Closed loop performance is obtained from the open loop performance by means of the Nicholls chart<sup>(2)</sup>.

The results of Table 3 Appendix (ii) have been plotted on Fig. 6 in terms of frequency and dB. The Nicholls chart allows both open and closed loops to be found. If this is done it will be seen that

Table III

<i>f.c.p.s.</i>	<i>Specified Amplitudes</i>	<i>Calculated Amplitudes</i>	<i>Experimental Amplitudes</i>
30	0.058 in. c. to pk.	0.058 in. c. to pk.	0.058 in. c. to pk.
40	0.0345	0.040	0.035
50	0.022	0.031	0.025
60	0.0155	0.021	0.020
80	0.0084	0.016	0.015
100	0.0055	0.011	0.008
150	0.0025	0.005	0.004
200	0.0014	0.0026	—

for unity feedback factor (*i.e.*  $K_3=1$ ) the system would be unstable when the loop is closed as in Curve A, Fig. 6. Moving curve A down until a gain margin greater than 6 dB and a phase margin greater than  $40^\circ$  is obtained, these gain and phase margin figures being normally considered adequate, loop stability is achieved. At 100 c.p.s. the open loop gain must be set at  $-6$  dB that is an amplitude ratio of 0.5. The present loop gain is  $-2.15$  dB (see Table 3) which corresponds to an amplitude ratio of 0.77.

Now the complete open loop gain is

$$15 \times 1.14 \times 0.77 K_3 = 0.5$$

$$K_3 = 0.038 \frac{\text{volts}}{\text{inch}}$$

The value of  $K_3$  must never be taken *carte blanche*, it must always be checked to see that the desired mass amplitude is obtained. This is done by defining at 30 c.p.s. (since that is the frequency at which the amplitude was set in Table 3,

Appendix (ii), column 6), that,

Forward gain

$$G(S) = K_1 K_2 \left| \frac{X_{02}}{i} \right| \\ = K_1 K_2 4.08$$

that is  $G(S) = 69.6 \frac{\text{ins.}}{\text{volt}}$

and Feedback gain

$$H(S) = 0.038 \frac{\text{volts}}{\text{inch}}$$

and the closed loop gain =  $\frac{G(S)}{1 + G(S)H(S)}$

$$= \frac{69.6}{1 + 69.6 \times 0.038} \\ = 25.4 \frac{\text{in.}}{\text{volt}}$$

Table IV

<i>f.c.p.s.</i>	<i>Experimental Results</i>		<i>Calculated Results</i>	
	<i>Phase</i>	<i>Gain dBs</i>	<i>Gain dB</i>	<i>Phase</i>
20	$-57^\circ$	$-0.5$	—	—
30	$-79$	$-2.5$	$-13$	$-108$
40	$-97$	$-4.0$	$-16$	$-123$
50	$-113$	$-5.7$	$-18$	$-135$
60	$-127$	$-7.0$	$-20$	$-146$
80	$-148$	$-11.0$	$-24.5$	$-164.7$
100	$-162$	$-14.0$	$-28$	$-179.4$
150	$-205$	$-26.0$	$-34$	$-203.8$
200	—	—	$-40$	$-239.4$

With the input voltage ( $V_{in}$ ) being 0.001 volt then  $x_{02} = 0.0254$  in.  $x_{02}$  should be 0.058 ins. at 30 c.p.s. and indicates that the feedback gain is too high.

To obtain the required mass amplitude a reduction in feedback gain is necessary.

At 30 c.p.s. the required output is 0.058 ins. for an input of  $\pm 1\text{mV}$ .

$$\text{Therefore closed loop gain} = \frac{0.058}{0.001} = 58 \frac{\text{in.}}{\text{volt}}$$

$$\text{Thus } \frac{G(S)}{1+G(S)H(S)} = 58$$

$$\frac{69.6}{1+69.6H(S)} = 58$$

$$\text{Therefore } H(S) = 0.00287 \frac{\text{volts}}{\text{inch}} = K_3$$

Therefore the open loop gain adjustment to Table III is

$$K_1 K_2 K_3 = 15 \times 1.14 \times 0.00287$$

$$= 0.049$$

$$= -26 \text{ dB} \text{ (see Table IV)}$$

A study of Table 4 Appendix (ii) and the Nicholls chart Fig. 6 reveals that at and above 8 c.p.s. the system is virtually open loop. This is the design objective where the feedback is only effective at low frequencies (that is frequencies below the bottom operating frequency of 30 c.p.s.) to prevent any long term drift of the ram and load. Equally important, since the closed loop response differs very little from the open loop response the amplitude-frequency results will be unaffected.

The final figures for gain and phase margins are 26 dB and  $85^\circ$  respectively which are more than adequate for stability.

### Comparison of Results

Table III lists the specified amplitudes with the calculated and experimental amplitudes for the purpose of comparison.

All experimental amplitudes were recorded using a single voltage setting. If required, the specified amplitudes could be achieved by reducing the gain of the system as the experimental results, with the exception of 30 c.p.s. were in excess of the amplitude specification.

Phase and gain experimental readings did not compare with their calculated readings too well although the shape of the Nicholls plot was similar, see Table IV.

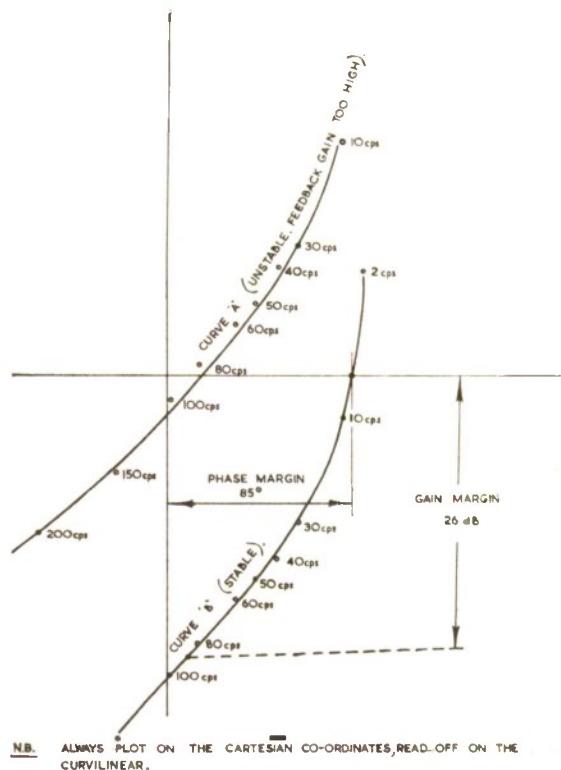


Fig. 6.  
Graph of the open loop which, when superimposed upon a Nicholls Chart indicates closed loop gain and phase margin.

If the experimental readings are plotted on the Nicholls chart it will be seen that there is too much forward gain in the system and that the closed loop phase and gain margins have been reduced from  $85^\circ$ , 26dB to  $70^\circ$ , 20dB respectively but still giving adequate loop stability.

### Conclusion

When translating design information into hardware it is important to realise that the 300 c.p.s. calculated frequency will be reduced by damping, leakage and losses through the valve which appear as a reduction of oil bulk modulus. Even though the frequency is higher than 200 c.p.s. there could be a significant phase shift at this frequency leading to instability if the gain is increased *ad lib* on other proposed systems where phase is important.

The statement regarding bleed orifices across the load is correct for this example but it may be necessary to introduce bleed damping when associated with higher or optimum loop gains and flat band response. This does however apply to larger ram areas, so that proportionality is a consideration.

Another point worth consideration is when the feedback element is fitted to the ram and not the load, bringing into play the term  $x_{01}$ . The forward loop transfer function will change from

$$\frac{x_{02}}{xi} = \frac{K_1 K_2}{\frac{A}{C_x} S \left\{ \left( \frac{M}{K} + \frac{VM}{4NA^2} \right) S^2 + (C_p + 2C_d) \frac{M}{2A^2} S + 1 \right\} \left\{ 1 + T_2 S \right\}}$$

$$\text{to } \frac{x_{01}}{xi} = \frac{K_1 K_2}{\frac{A}{C_x} S \left\{ \frac{VM}{4NA^2} S^2 + (C_p + 2C_d) \frac{M}{2A^2} S + 1 \right\} \left\{ 1 + T_2 S \right\}}$$

which by deletion of the  $\frac{M}{K}$  term will affect the loop stability since any resilience between the ram and the load denoted by the stiffness term  $K$  in Fig. 3 does produce some phase difference.

The theoretical analysis used in evaluating the system response is one that gives good agreement between theory and practice but it must be remembered that valve controlled hydraulic systems are essentially non-linear in the mathematical sense which leads one to reflect that there is still much to be done in this field.

### Acknowledgement

The authors wish to thank the Captain Superintendent, A.U.W.E. and Dowty Rotol Ltd., for the opportunity to carry out this work and for permission to publish their findings. The help and assistance so readily given by the staff of both establishments is also appreciated.

### References

- (1) N. F. Harpur. Proceedings of Conference on Hydraulic Servo-Mechanisms. 13th February, 1953.
- (2) Further Uses of the Nicholls Chart. Data Sheet 27 Control. February, 1963.

### Appendix (i)

See Reference (1).

The objective is to determine a transfer function of the complete system, that movement of the mass  $M$  in inches divided by the signal source input to the servo amplifier in volts.

Initially consider the relationship between the second stage spool movement and the subsequent ram movement. See Fig. 3.

The flow into the ram through the valve ports is

$$Q_1 = f(X_1, P_s - P_1)$$

Similarly the flow out of the ram

$$Q_2 = f(X_1, P_2 - P_r)$$

If the ports are symmetrical the function in both cases will be the same, otherwise it will depend on the geometry of the ports. In general the flow is approximately proportional to the square root of the pressure drop across the port and may be written as

$$Q_1 = \alpha X_1 \sqrt{P_s - P_1} \quad \dots (1)$$

$$Q_2 = \alpha X_1 \sqrt{P_2 - P_r} \quad \dots (2)$$

The flow to one side of the ram may now be considered in more detail.

Since the bulk modulus of the fluid is defined as

$$N = -V \frac{dP}{dV} \quad \dots (3)$$

for a given mass of fluid  $M^1$ , occupying a volume  $V$ .  $N$  is a constant for oil free from entrained air and for D.T.D. 585 is generally taken as  $2 \times 10^5$  lbs./ins.<sup>2</sup>

$$\text{Now } V = \frac{M^1}{p} \text{ where } p \text{ is the density of the fluid}$$

$$\text{Therefore } \frac{dV}{dp} = \frac{-M^1}{p^2}$$

$$\text{and therefore } N = \frac{M^1 dP}{p dp M^1} = p \frac{dP}{dp}$$

$$\text{and } \frac{1}{p} dp = \frac{1}{N} dP \quad \dots (4)$$

Differentiating this with reference to time gives,

$$\frac{1}{p} \frac{dp}{dt} = \frac{1}{N} \frac{dP}{dt}$$

Now the mass of oil on one side of the ram at any time is

$$M_1^1 = p_1 V_1$$

and differentiating with respect to time gives

$$\frac{dM_1^1}{dt} = \frac{V_1 dp_1}{dt} + \frac{p_1 dV_1}{dt}$$

Thus the volume flow into this side of the ram is

$$Q_1 = \frac{1}{p_1} \frac{dM_1^1}{dt} = \frac{V_1 dp_1}{p_1 dt} + \frac{dV_1}{dt}$$

which from Equation (4)

$$Q_1 = \frac{V_1}{N_1} \frac{dP_1}{dt} + \frac{AdX_{01}}{dt} \quad \dots (5)$$

Similarly, it may be shown that the flow out of the other side of the ram is

$$Q_2 = \frac{V_2}{N_2} \frac{dP_2}{dt} + \frac{A dX_{01}}{dt} \quad \dots (6)$$

This analysis assumes that the time taken for a pressure wave in the fluid to travel from the valve to the ram is small compared with the period of any oscillations under consideration. Furthermore Equations (5) and (6) do not allow for any valve underlap or neutral leakage or the incorporation of a bleed hole for damping. An additional equation is therefore added to allow this effect to be included, namely

$$Q_3 = \beta \sqrt{P_1 - P_2} \quad \dots (7)$$

And equations (5) and (6) become

$$Q_1 = \frac{V_1}{N_1} \frac{dP_1}{dt} + \frac{A dX_{01}}{dt} + Q_3 \quad \dots (8)$$

$$Q_2 = \frac{-V_2}{N_2} \frac{dP_2}{dt} + \frac{A dX_{01}}{dt} + Q_3 \quad \dots (9)$$

The next stage is a consideration of the loads on the ram, the external load being:

$$\text{Force} = (P_1 - P_2)A$$

The load produced by the inertia of the mass acting on the ram is

$$F = \frac{M d^2 X_{02}}{dt^2}$$

$$\text{Therefore } P_1 - P_2 = \frac{M}{A} \frac{d^2 X_{02}}{dt^2} \quad \dots (10)$$

If the linkage between the ram area and the mass  $M$  is not considered as completely rigid but having some resilience as shown in Fig. 3 by a spring connection possessing a stiffness  $K$  then,

$$F = (P_1 - P_2)A = K(X_{01} - X_{02}) = \frac{M d^2 X_{02}}{dt^2} \quad \dots (11)$$

All the preceding equations define the motion and to solve them it is necessary to consider only small perturbations about a steady state condition.

Therefore  $X_i$  is replaced by  $X_i + x_i$

$$\begin{aligned} X_{01} & \dots & X_{01} & + x_{01} \\ X_{02} & \dots & X_{02} & + x_{02} \\ Q_1 & \dots & Q_1 & + q_1 \\ Q_2 & \dots & Q_2 & + q_2 \\ Q_3 & \dots & Q_3 & + q_3 \\ P_1 & \dots & P_1 & + p_1 \\ P_2 & \dots & P_2 & + p_2 \end{aligned}$$

Also the simplifying assumptions of constants  $P_s$  and  $P_r$  will be made and  $P_r$  be taken as zero.

Equations (1), (2), (7), (8), (9) and (10) now become

$$Q_1 + q_1 = \alpha X_i \sqrt{P_s - P_1} + \frac{\partial Q_1}{\partial X_i} x_i + \frac{\partial Q_1}{\partial P_1} p_1 \quad \dots (12)$$

$$Q_2 + q_2 = \alpha X_i \sqrt{P_2} + \frac{\partial Q_2}{\partial X_i} x_i + \frac{\partial Q_2}{\partial P_2} P_2 \quad \dots (13)$$

$$Q_1 + q_1 =$$

$$\frac{V_1 dP_1}{N_1 dt} + \frac{AdX_{01}}{dt} + \frac{V_1 dp_1}{N_1 dt} + \frac{Adx_{01}}{dt} + (Q_3 + q_3) \quad \dots (14)$$

$$Q_2 + q_2 =$$

$$\frac{V_2 dP_2}{N_2 dt} + \frac{AdX_{01}}{dt} + \frac{V_2 dp_2}{N_2 dt} + \frac{Adx_{01}}{dt} + (Q_3 + q_3) \quad \dots (15)$$

$$Q_3 + q_3 = \beta \sqrt{P_1 - P_2} + \frac{\partial Q_3}{\partial P_1} P_1 - \frac{\partial Q_3}{\partial P_2} P_2 \quad \dots (16)$$

$$P_1 - P_2 + p_1 - p_2 = \frac{M d^2 X_{02}}{A dt^2} + \frac{M d^2 x_{02}}{A dt^2} \quad \dots (17)$$

Eliminating the steady state terms from the above equations will result in the equations for small perturbations only.

$$q_1 = \frac{\partial Q_1}{\partial X_1} x_i + \frac{\partial Q_1}{\partial P_1} p_1 \quad \dots (18)$$

$$q_2 = \frac{\partial Q_2}{\partial X_1} x_i + \frac{\partial Q_2}{\partial P_2} p_2 \quad \dots (19)$$

$$q_1 = \frac{V_1 dp_1}{N_1 dt} + \frac{A dx_{01}}{dt} + q_3 \quad \dots (20)$$

$$q_2 = \frac{-V_2 dp_2}{N_2 dt} + \frac{A dx_{01}}{dt} + q_3 \quad \dots (21)$$

$$q_3 = \frac{\partial Q_3}{\partial P_1} p_1 - \frac{\partial Q_3}{\partial P_2} p_2 \quad \dots (22)$$

$$p_1 - p_2 = \frac{M d^2 X_{02}}{A dt^2} \quad \dots (23)$$

The equations (18) to (23) are now linear although the co-efficients

$$\frac{\partial Q_1}{\partial X_i}, \frac{\partial Q_1}{\partial P_1}, \frac{\partial Q_2}{\partial X_i}, \frac{\partial Q_2}{\partial P_2}, V_1, N_1, V_2 \text{ and } N_2$$

are functions of the steady state condition at which the system is being studied. In the steady state condition the flows into and out of the ram will be equal and in general therefore, with symmetrical valve porting

$$\frac{\partial Q_1}{\partial X_i} = \frac{\partial Q_2}{\partial X_i} = C_x, \text{ say}$$

$$\frac{-\partial Q_1}{\partial P_1} = \frac{\partial Q_2}{\partial P_2} = C_p$$

$$\text{and } \frac{\partial Q_3}{\partial P_1} = \frac{\partial Q_3}{\partial P_2} = C_d$$

To simplify the analysis at this stage the case where the ram is at mid-stroke will be considered, that is  $V_1 = V_2 = \frac{V}{2}$  where  $V$  is the total volume, also that  $P_2$  is high enough greater than 500 lbs. sq. in. say to put  $N_1 = N_2 = N$  since the effects of air in the oil will be negligible.

Thus from equations (18) and (20)

$$q_1 = C_x x_i - C_p p_1 = \frac{V}{2N} \frac{dp_1}{dt} + \frac{A dx_{01}}{dt} + q_3 \dots (24)$$

and from (19) and (21)

$$q_2 = C_x x_i + C_p p_2 = \frac{-V}{2N} \frac{dp_2}{dt} + \frac{A dx_{01}}{dt} + q_3 \dots (25)$$

similarly

$$q_3 = C_d (p_1 - p_2) \dots (26)$$

also referring back to equation (11)

$$F = A(p_1 - p_2) = K(x_{01} - x_{02}) \dots (27)$$

$$= \frac{Md^2 x_{02}}{dt^2} \dots (28)$$

Equations (24) to (28) inclusive are small signal equations and are all that are necessary to determine the performance of the hydraulic sections being considered.

## Appendix (ii)

### Introduction to Table I

Consider the equation

$$\frac{x_i}{i} = \frac{K_2}{1 + T_2 S} = \frac{1.14}{1 + 0.0017S}$$

$T_2$  is the time constant of the valve, published by the valve manufacturer, see Fig. 3.

Considering the frequency dependent term only (i.e.  $K_2$  is not considered at this stage), and putting  $S = j\omega$  and rationalising we have

$$\frac{x_i}{i} = \frac{1}{1 + 0.0017j\omega} \text{ that is } \frac{x_i}{i} = \frac{1}{1 + j\omega T_2}$$

To rationalise we have to multiply both numerator and denominator by  $1 - j\omega T_2$

thus,

$$\frac{1}{1 + j\omega T_2} \times \frac{1 - j\omega T_2}{1 - j\omega T_2} = \frac{1 - j\omega T_2}{1 - \omega^2 T_2^2} \text{ (since } j^2 = -1\text{)}$$

Arranging in the form  $a - jb$  we have

$$\frac{1}{1 + \omega^2 T_2^2} - j \frac{\omega T_2}{1 + \omega^2 T_2^2}$$

$$a - j b$$

### Example

For  $f = 30 \text{ c.p.s.}$ ,  $\omega = 2\pi f = 188 \text{ rads./sec.}$

$$T_2 = 0.0017$$

$$\omega T_2 = 188 \times 0.0017 = 0.319$$

$$\omega^2 T_2^2 = 0.319^2 = 0.102$$

Therefore  $a =$

$$\frac{1}{1 + 0.102} = \frac{1}{1.102} = 0.91 \text{ and } a^2 = 0.91^2 = 0.828$$

$$b = \frac{0.319}{1 + 0.102} = \frac{0.319}{1.102} = -0.29 \text{ and } b^2 = -0.29^2 = 0.0841$$

$$\text{Now } \left| \frac{x_i}{i} \right| =$$

$$\sqrt{a^2 + b^2} + \sqrt{0.828 + 0.0841} = \sqrt{0.9121} = 0.956$$

$$\text{And } \phi = \tan^{-1} \frac{b}{a} = \frac{-0.29}{0.91}$$

$$= \tan^{-1} -0.319 \text{ therefore } \phi = -17.7^\circ$$

Thus for  $\omega = 188 \text{ rads./sec.}$  the modulus of  $\frac{x_i}{i} = 0.956$  and its phase is  $-17.7^\circ$ .

It is also useful to express the modulus in dBs since dB addition of each transfer function is the equivalent of multiplication of function in cascade i.e. one transfer function feeding into another. Fig. 5 explains this point in diagrammatic form.

For dBs then:

$$\text{dBs} = 20 \log 0.956$$

$$= 20 \times 1.9805 = 20 \times -0.0195$$

Therefore

$$\text{dBs} = -0.390$$

When each frequency has been solved in modulus, phase and dBs the following table emerges.

### Introduction to Table 2

To compile Table 2 we must solve the following equation

$$\frac{x_{02}}{x_i} =$$

$$\frac{1}{\frac{A}{C_x} S \left( \left( \frac{M}{K} + \frac{VM}{4NA^2} \right) S^2 + (C_p + 2C_d) \frac{M}{2A^2} S + 1 \right)}$$

Table 1

f.c.p.s.	W. rads./sec.	$\frac{xi}{i}$	dBs	$\phi$ degrees
30	188	0.956	-0.390	-17.7
40	251	0.92	-0.724	-23.0
50	314	0.884	-1.070	-28.1
60	377	0.84	-1.514	-32.6
80	502	0.76	-2.384	-40.5
100	628	0.685	-3.286	-46.9
150	941	0.53	-5.514	-49.2
200	1256	0.423	-7.474	-65.4

Example

For  $f=30$  c.p.s.,  $w=188$  rads./sec.

Substituting the following values,

$$\zeta=0.8 \quad T_1=0.73 \times 10^{-3} \text{ secs.}$$

$$\alpha=0.129 \times 10^{-2} \quad w=188 \text{ rads./sec.}$$

$$\text{then } A=2 \times 0.8 \times 0.73 \times 10^{-3} \times 0.129 \times 10^{-2} \times 188^2$$

therefore  $A=0.0535$  and  $A^2=28.6 \times 10^{-4}$ .

$$B=(188 \times 0.129 \times 10^{-2} - 0.129 \times 10^{-2} \times 0.73^2 \times 10^{-6} \times 188^3)$$

$$=0.242 - 0.00457$$

Therefore  $B=0.2374$  and  $B^2=0.0563$

Using  $\frac{-A}{A^2+B^2} - j \frac{B}{A^2+B^2}$  we have,

$$= -\frac{5.35 \times 10^{-2}}{28.6 \times 10^{-4} + 56 \times 10^{-3}} - j$$

$$= -0.94 \quad \frac{23.74 \times 10^{-2}}{28.6 \times 10^{-4} + 56 \times 10^{-3}} - j 4.16$$

$$\left| \frac{x_{02}}{xi} \right| = \sqrt{-0.94^2 - 4.16^2} = 4.26$$

$$\text{and } \tan \phi = \frac{-4.16}{-0.94} = \tan^{-1} 4.42 = 77.2^\circ$$

therefore  $\phi = -180 + 77.2$  therefore  $\phi = -102.8^\circ$

Substituting for each frequency yields Table 2.

Table 2

f.c.p.s.	W rads./sec.	$\left  \frac{x_{02}}{xi} \right $	dBs	$\phi$ degrees
30	188	4.26	12.59	-102.8
40	251	3.06	9.71	-106.7
50	314	2.44	7.75	-111.2
60	377	2.02	6.10	-115.9
80	502	1.47	3.35	-124.2
100	628	1.14	1.14	-132.5
150	941	0.674	-3.426	-154.6
200	1256	0.438	-7.170	-174.0

Combined Response (Table 3)

The responses given in Table 1 and 2 are now combined by adding the dB ratios pertaining to individual frequencies, similarly the phase angles.

The modulus,  $\left| \frac{x_{02}}{xi} \right|$  must be multiplied.

The combined response is  $\frac{x_{02}}{i}$

$$\text{since } \frac{xi}{x} \times \frac{x_{02}}{xi} = \frac{x_{02}}{i}$$

$$\text{Hence } \left| \frac{x_{02}}{xi} \right| = \sqrt{a^2 + b^2}$$

Table 3

<i>f.c.p.s.</i>	<i>W. rads./sec.</i>	$\left  \frac{x_{st}}{x_i} \right $	<i>dBs</i>	$\phi$ degrees	<i>Amplitude of mass M set at 0.058 ins. at 30 c.p.s</i>
30	188	4.08	12.20	-120.5	0.058 ins. c. to pk.
40	251	2.82	9.00	-129.7	0.040
50	314	2.16	6.68	-139.3	0.031
60	377	1.70	4.59	-148.5	0.024
80	502	1.12	0.97	-164.1	0.016
100	628	0.78	-2.15	-179.4	0.011
150	941	0.36	-8.94	-203.8	0.005
200	1256	0.19	-14.64	-239.4	0.0026

Table 4

<i>f.c.p.s.</i>	<i>W. rads./sec.</i>	$\left  \frac{x_{st}}{x_i} \right $	<i>dBs</i>	$\phi$ degrees	<i>Open Loop Adjustment</i> $K_1 K_2 K_3 = 26 \text{ dB}$	<i>Closed Loop</i> <i>dBs</i>	<i>ϕ</i>
30	188	4.08	12.20	-120.5	-13.8	-13	-108
40	251	2.82	9.00	-129.7	-17.0	-16	-123
50	314	2.16	6.68	-139.3	-19.32	-18	-135
60	377	1.70	4.59	-148.5	-21.41	-20	-146
80	502	1.12	0.97	-164.7	-25.03	-24.5	
100	628	0.78	-2.15	-179.4	-28.15	-28	
150	941	0.36	-8.94	-203.8	-34.94	-34	
200	1256	0.19	-14.64	-239.4	-40.64	-40	As Column 5

Column 6 of Table III has been added as a check to the centre to peak amplitudes required by the specification in Table 1. By setting the mass

amplitude of 0.058 in. at 30 c.p.s. then for example, at 40 c.p.s. the amplitude will be  $12.2 - 9.0 = 3.20$  dB less i.e. 0.04 in. c. to pk.

# Scientific Service to Management

By R. W. Robinson, A.I.M.

*Dockyard Laboratory, Devonport*

## Introduction

An international authority recently stated that "Present technical problems are less a matter of generating new ideas than of carrying them out in a straightforward, methodical and painstaking manner. Only in this way can the new scientific advances be trained to practical use".

This highlights the long recognised gulf between fundamentalists and the practising scientist or engineer, and one of the important functions of an effective Dockyard Laboratory must be to help bridge the gap between the two worlds so far as materials are concerned.

Science in the Royal Dockyards provides an essential aid to management in the establishment of a fundamentally sound partnership of design, production and development essential to the advance of the Navy into the New Age in which "quality is the never ending challenge".

## Historical

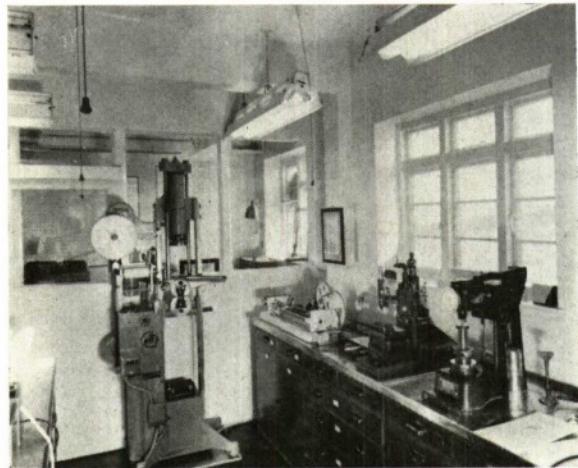
The laboratory in Devonport Dockyard was founded in 1936 as a small foundry control service of very limited scope and continued as such until the end of the war when the R.N.S.S. was formed. There followed a gradual increase in activity until at the end of 1951 it became apparent that a considerable re-organisation was essential if the needs of the altering pattern in the Dockyard and the post war Fleet were to be satisfied. A process of change was initiated which has progressed concurrently with changes elsewhere. Initially the expansion was confined to the Engineering Department but sight was never lost of the long term concept of a Dockyard Scientific Unit serving the needs of all departments and of the Fleet in the Plymouth Command.

To achieve such a change was not easy and involved a good deal of re-thinking on the part of Management, and those responsible for Technical Supervision and science. The process was hampered by lack of laboratory accommodation and by shortage of staff, but gradual inroads were made into the widely differing fields of Dockyard activity and to the establishment of firm links with Headquarters Sections, and with the larger

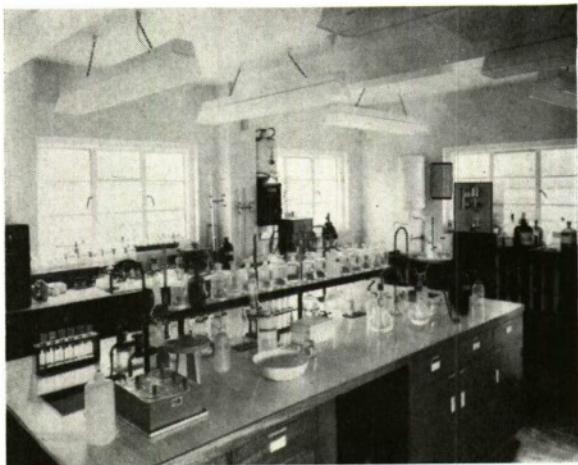
Specialist Laboratories, thereby bringing an increased scientific potential to bear.

At the end of 1962 the process was sufficiently far advanced to enable the scientific team to receive a new mandate and appropriate orders were issued by the Commander-in-Chief, Plymouth, and Admiral Superintendent, Devonport, confirming the new status and responsibility of the now recognised Dockyard Laboratory. This basic authority was further endorsed by the issue of internal Administrative Orders by the Managers of the other production departments, along the lines of those already promulgated by the Manager, Engineering Department thereby giving formal recognition and authorising the scientific team to operate within their jurisdiction. During 1963 approval was forthcoming for the completion of the post-war laboratory and an extensive programme of re-organisation was undertaken. The completed building now embraces over 4,500 sq. ft. as compared with the 500 sq. ft. of the original premises. Due to unpredictable changes the actual growth of work has risen considerably above that anticipated and steps are now being taken to provide the additional space required. The rate of change is illustrated by the rising level of work and a figure of 1,500 items a year is now being approached as compared with the 200 items when the re-organisation commenced. During the past five years an annual growth of 12.5% has been maintained.

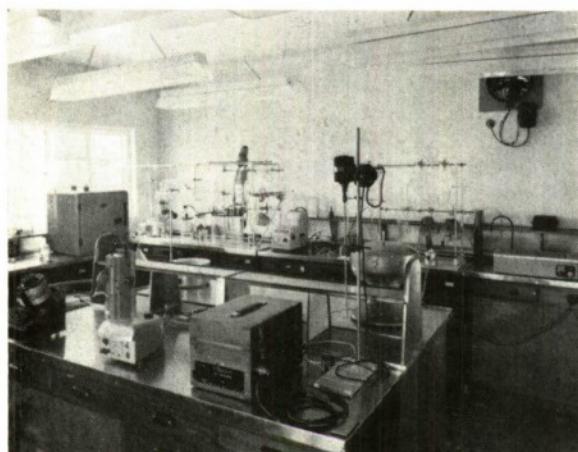
A Dockyard Laboratory requires a balanced team consisting of scientists qualified in the appropriate fields and at the appropriate levels, supported by mechanic grades and a photographic and clerical complement. In consideration of its functions due regard must be paid to the special needs of such an establishment in the scientific field and it should be emphasised that one of the most significant differences between a Dockyard scientific unit and the larger Research Establishments is that much of the work is of necessity closely related to production dates. It is, therefore, seldom possible to postpone or delay items for very long and most tasks must be progressed forthwith or left unresolved, the latter course being to the



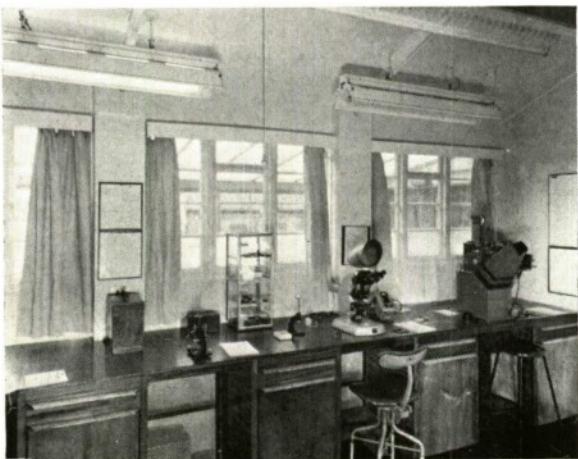
*Mechanical testing section.*



*The new chemical laboratory.*



*The physical chemistry laboratory.*



*A view of the metallurgical laboratory.*

detriment of the Fleet. It is essential also to achieve a balance between routine and development work, so ensuring that the scientific team retains a progressive outlook. The scientific complement in Devonport consists of members of the Royal Naval Scientific Service, the Admiralty Photographic Service and permanent industrial staff. The laboratory is divided into metallurgical, chemical, projects, photographic and workshop, sections housing a wide range of equipment, added to as necessary, and supplemented by excellent machine tool and testing facilities. Additionally, facilities exist for corrosion and paint testing and these include an aerial exposure site, a large corrosion tank and a raft moored adjacent to the Plymouth Breakwater, thus providing useful adjuncts to the laboratory and to the Central Dockyard Laboratory organisation.

### The Organisation

Although some readers of this article will be familiar with a Royal Dockyard, a brief description of the wide scope of the work performed in Devonport Yard may be worthwhile. The range of activity includes the construction of frigates and the modernisation of aircraft carriers. The latter presents an enormous task and may involve almost complete re-building and rehabilitation. The refitting of submarines, cruisers, destroyers, *etc.*, is also undertaken in addition to a multitude of small craft whilst the various sections are from time to time employed in the production of components for other yards, *e.g.* foundry castings, weld fabrications, piston reclamations, *etc.*

From the foregoing it will be seen that the scientific team can be involved in a very wide range of industrial processes, many of which involve a high degree of specialisation.

Devonport Yard retains much of its traditional form and is not at present the subject of advanced functionalization. Certain new organisations have, however, emerged, such as Planning, Ship Scheduling, Method Study, Material Co-ordination Group, *etc.*, and the Yard is moving towards re-organisation, *e.g.* by bringing together the personnel sections.

The Yard is administered by an Admiral Superintendent with the traditional Departmental Management Structure but now including a Finance Manager. Some 18,000 workpeople are employed and in this respect it is the largest of the Home Dockyards.

The Devonport Laboratory is part of the C.D.L. organisation and is staffed and administered professionally by the Superintending Scientist, Portsmouth. Local administration is under the aegis of the Engineer Manager, but the Officer-in-Charge, as has been stated previously, is authorised to

operate independently and provide a service to all departments and to the Fleet and Naval Establishments within the Plymouth Command. This new position represents the most significant change in the post-war period and presents a new concept of applied science. It will be readily appreciated that the scientific requirements of a modern Dockyard have changed very considerably due to the wide range of materials involved and the complex processes employed, and in order to give a full service it is essential to co-operate with other Scientific Establishments, where information and staff specialised in particular fields are available. The Laboratory has endeavoured to play an active role in a two way interchange of information and acts as a feeder unit for certain of the larger establishments. Where a problem is incapable of resolution from its own resources, reference is made to the parent C.D.L. or to the appropriate specialist laboratory whose function it is to carry out such work.

### Scope of Activities

The general scope of work is outlined in the attached chart and will be seen to be widely varying in character. In summary, it can be stated that there is a fairly even balance between the evaluation of service failures, corrosion problems, production control and short term development and research of an applied character.

The varied nature of the work undertaken by the scientific staff has already been referred to and is further amplified below. Reference is made to the financial aspect which must figure increasingly in defence projects. Such items as the reclamation of large submarine light alloy diesel engine pistons, the development from a non-operational basis to a high productivity unit of the heavy electro-plating plant, the chemical de-scaling of submarine diesel engine cylinder heads, the cathodic protection of large steel shell calorifiers, and the 'in situ' cleaning of air conditioning units in aircraft carriers provide ample evidence of the type of co-operation achieved between the Yard sections and the laboratory.

The reports of investigation of service failures, *etc.*, have a wide circulation and in order to obtain the optimum benefit from the work undertaken, copies are forwarded to the parent laboratory in Portsmouth, to H.Q.'s sections, Fleet Maintenance Authority, the Dockyard Department concerned, the ship and Class Authority and as appropriate to the M.O.D.(N) Committees (C.P.C.&F., Boiler Corrosion, *etc.*).

The scientific team are also making an increasing contribution in the Yard re-fit programme and the service given commences with gas free certification of tanks and includes such items as safety

## Scope of Activities

<u>Service Failures</u>	<u>Quality Control</u>	<u>Development</u>	<u>Field Services</u>
Metallurgical and Chemical examinations	Electro plating Welding	Evaluation and service Trials of new materials	Flaw detection Gas testing of fuel tanks etc.
Report Production incorporating recommendations for design changes as appropriate	Foundry items Heat treatment Oil testing Alloy identification Pickling etc.	Introduction of new or modified repair and production processes Corrosion problems (Evaluation and remedial measures)	Hydrogen trials in submarines Pyrometric testing Chemical cleaning processes in ships and shops Resin treatments Analysis of deposits General information on scientific problems Corrosion testing sites (Aerial and raft)
Liaison with headquarters sections, ship and yard Departments and other laboratories. (CDL, BRAGG, AML, AOL . . . )	Photography with a scientific emphasis (Colour and black and white) Cinematography		

clearance of compartments treated with high volatile compositions, rehabilitation of certain machinery components which continue to deteriorate very badly in service (this includes pretreatments and protective coatings, resins, etc.), examination of specific service failures and recommendations for palliative measures to be incorporated into the replacement components, production control of welding (frequently involving sophisticated materials), the reclamation of machinery components such as turbine rotors, journals, etc. by heavy plating, crack detection, the deployment of new materials and hydrogen trials in H.M. Submarines.

### Evaluation of Service Failures

Where a component has suffered failure in service without apparent cause it is important that the item should be examined in order to determine the mode and reason for the failure. It is then essential that the information derived, together with any recommendations regarding changes in design-geometry, material, fabrication, protection, should be made available to the interested authorities.

It may be worthy of mention that, broadly speaking, experience gained from the examination of over 1,000 failed components in Devonport suggests that premature failures resulting from compositional discrepancies are extremely rare, and unsatisfactory service performance can, more often than not, be related to an unsuitable choice of material for a particular service, inadequate quality control during

manufacture or assembly, or lack of suitable maintenance during operation. Typical laboratory items in this field are discussed below.

### *Cracking of Light Alloy Pistons in A.S.R.I Diesel Engines*

Following the failure of one piston in service the comprehensive examination of a large number of items from four ships was undertaken and revealed the existence of numerous crack systems due to fatigue, and served to highlight a major design weakness in the crown of the pistons. Modifications have now been introduced into all new pistons.

### *Corrosion of Attachment Bolts for Light Alloy Roofing Sheets*

The introduction of aluminium alloy cladding to aircraft hangars at a Naval Air Station was followed by a number of attachment bolt failures due to corrosion, resulting in detachment of sheeting. This was due to the use of zinc electro-plated steel and a further feature was the gross discolouration of the hangars due to rust deposits. The recommendation made resulted in a national change in policy by industry and the introduction of aluminium alloy fastenings for this service.

### *Cracking of Turbo-Blower Stator Blades*

Repeated cracking encountered in these components has been attributed to an original design weakness, accelerated by indifferent fabrication by

welding. Rebuilt components are now in service incorporating the following modifications:—

- (a) Heavier gauge metal sheet.
- (b) Full penetration and continuous welding.
- (c) Stiffening of flanges by gusset plates to reduce vibration.
- (d) Protection of metal with epoxy resin surface coatings.

### Field and Development Work

The new terms of reference emphasise the importance of the field aspect of scientific work and the staff are frequently called upon to assist and advise on problems arising in the Dockyard and in other sections of the Command.

The work undertaken under this heading is not fundamental or even new in the fullest sense of the term, but is of considerable importance since it relates to applied science or science at the "coal face". One further aspect of this branch of Dockyard Science lies in the fact that far too often the value of worthwhile fundamental work is lost or unduly delayed in effect because of failure to apply in practice the knowledge gained. The laboratory seeks to bridge this gap by liaison with Yard Sections so giving publicity to a particular project or by development work inspired of its own accord.

For the purpose of discussion the work is subdivided into the following:—

- (a) Application of new materials and processes for specific services.
- (b) Reclamation of worn or damaged components which would hitherto involve replacement.
- (c) Re-examination of established practices to evolve more efficient techniques with consequent improvement in quality and economies in time and money.

The undermentioned items are representative of the type of development work sponsored and undertaken, some of which has already been recognised and approved, whilst other items are still undergoing service trials. All projects are recorded and the Ship's Officers concerned are requested to forward periodic reports on their operational performance.

In the first category it is considered appropriate to mention the introduction of nylon propellers to harbour launches. The rate of deterioration of small H.T. brass propellers can reach extraordinary proportions, particularly where stainless steel shafts are fitted, and it is not unknown for service life to be measured in hours. Selective corrosion and/or cavitation erosion are the principal reasons for failure, but damage by impact with floating debris is frequent.

The use of nylon has resulted in a remarkable increase in life. Furthermore, since the blades are

detachable, damage by impact can be readily remedied by the replacement of individual blades.

Service trials were arranged at Britannia Royal Naval College, Dartmouth, the results of which were of value in enabling M.O.D.(N) to make a decision to extend their use throughout the service.

Extensive development work has been carried out into the use of epoxy and other resins particularly for those applications where corrosion is the principal form of deterioration. Some problems have been experienced with the adhesion of the coatings, particularly at perimeters, but trials have shown that an excellent performance is achieved when it is possible to shot blast and metal spray the surface prior to the application of resin. The porous nature of the sprayed layer provides an ideal key for the coating and the method has been adopted for the protection of aluminium alloy engine sumps, evaporator shells, critical sections of sea water circulating systems and eroded cast iron cylinder liners. The use of epoxy resin laminates has also been extended to submarine exhaust bend water jackets with encouraging results.

Two examples in the second category are provided by the reclamation by Argon Arc Welding of worn "A" and "T" Class submarine main engine pistons, and the modernisation of the heavy electro-plating plant in M.E.D., Devonport.

With reference to the reclamation of light alloy pistons the principal region of wear in service is in the vicinity of the ring grooves and this would normally necessitate replacement. A method was evolved for the building up of the ring grooves by welding using a matching filler rod followed by re-machining of the grooves. The technique was applied to *Lo-Ex* pistons in the first instance and extended to "Y" alloy components following minor modifications. A reclaimed piston was examined dimensionally and destructively after a service trial of over 2,000 running hours and was shown to be in excellent condition.

M.O.D.(N) has now issued instructions that all worn pistons be sent to Devonport for reclamation by this technique.

The lack of facilities for the reclamation of worn components such as turbine rotors, pump shafts, etc., presented a considerable problem to management, and frequently involved considerable delays in refits. Little assistance was forthcoming from industry regarding plating techniques, and the complete re-habilitation of the plant had to be tackled from local sources. This involved a re-appraisal of workshop hygiene, employment of new plating solutions, trials in anode deployment and current distribution, and the purchase of power sources and other equipment. A system of scientific control was introduced and the results have

been most satisfying. The plant can now cope with most of the requirements of Dockyard work.

In the final category, the type of work undertaken is best illustrated by reference to trials carried out into metal spray techniques, which evaluated the conditions essential to ensure good adhesion. The work covered such variables as spray gun angle and range, surface preparation and other environmental factors such as gas control, etc. The knowledge gained was utilised in the building up of worn gun metal liners fitted to the propeller shafts of a frigate and it has recently been learned that the spray coating remained entirely satisfactory after steaming 50,000 miles.

An additional example in Category 3 concerned the cathodic protection of three large steel shell calorifiers which, after only two years of life, and in spite of extensive chemical palliative measures by industry, had sustained pitting to a depth of 40% of the plate thickness. In view of the character of local fresh water which is almost within the "pure" category, there seemed little prospect of success, but experiments over a period of several months evolved an anode system using magnesium and an impressed supply current of approximately 30V which solved the problem completely, and these items now have indefinite life with a considerable financial saving.

### **Production and Quality Control**

Particular attention has been given to production and quality control in order to ensure that a much improved scientific contribution is made in the industrial field and a series of control procedures have been developed in Devonport which are considered to have played a significant part in the improvement of both quality and output. As the range of materials employed in the Naval service increases, this aspect of Dockyard Science must grow in importance if the essential standards are to be maintained.

In elaboration of the above, specific mention is made of the work of the laboratory in respect of:—

*Welding* which has been given particular attention. Information is supplied concerning the composition of materials, correct type of electrode or filler wire and flux to be used, and the metallurgical factors involved including the all important question of thermal treatment. Frequently recommendations are made which result in modification to design of components, e.g. welding of thermometer pockets where a wide variation of materials had been in use, causing serious problems in the production of sound and crack free welds. In this instance a material modification has been proposed.

### **Foundry Control**

The service available to the foundry includes the metallurgical control of the production of cast iron and non-ferrous alloys (microscopic control, etc.), chemical analysis, sand control, advice on casting techniques, calibration and testing of pyrometric equipment.

### **Heavy Plating Control**

On completion of development of the heavy plating plant control passed to the appropriate production section, a watching brief is, however, retained over its activities and is available to investigate the occasional failures which occur and advise on the remedial measure to be taken.

### **Forging and Heat Treatment**

The increasing wide range of materials in use demands close liaison between the laboratory and the production centres, and information is frequently given concerning forging techniques and heat treatment procedures.

### **Metal Spray Processes**

Following numerous failures in service of sprayed coatings the laboratory has undertaken a thorough investigation into the techniques involved and has made recommendations for process control to achieve a consistently sound product.

### **Crack Detection of Main Propulsion Machinery Items**

An extensive service has been provided in the field of crack detection over the past twelve years and such items as submarine main engine frames, turbine bearing pedestals, boiler room fans, main reduction gear casings, and the massive survey of A.S.R.1. diesel engine components have received attention, in many instances supported by metallurgical investigation. The information provided has frequently had an appreciable effect upon future design and influenced decisions of operational significance.

### **The Future**

Whatever the future role of the Royal Naval Scientific Service in the defence structure the Dockyard Laboratories cannot lose their identity nor their close association with the Fleet. It seems clear also that the need for a highly efficient scientific component with an industrial bias will grow concurrently with advances in the technological field, and with the introduction of new and sophisticated materials necessary to satisfy the new design requirements brought about by such evolutionary and fundamental changes as, for example, the upward rise in steam temperatures and pressures.

Increased water circulation speeds (and turbulence), higher operating temperatures, use of new operating media (fuels, coolants, etc.), longer intervals between maintenance, the use of larger aircraft and higher landing speeds, and shortly the even more advanced technologies associated with nuclear propulsion and the new weapons systems are further advances which need to be considered.

Although we have fewer ships in the post-war Navy they are infinitely more complex in character, both for propulsion and fire power. There is an ever increasing need for the ultimate in reliability and ability to remain "on station" for prolonged periods, whilst at the same time providing much improved standards of habitability, so curtaining the space available for machinery and other equipment. Additionally, the enormous cost of defence demands "value science" in the broadest sense, with the emphasis upon prevention rather than cure. The dockyard scientist has a vital role to play in these matters. In spite of all the technological advances made in recent years there is a need for constant vigil if the intensity of premature failures and the rate of deterioration which occurs in the Naval service is to be contained and held at an acceptable level. Some of the problems experienced may be related to the increased specialisation demanded of ships' staffs, with the resultant reduction in the "free labour force", and consequential limitations in routine maintenance, but it is also evident that much remains to be achieved in the production and design fields. This necessitates closer co-operation between those at the "coal face" in Dockyards, Ships' Staffs and Research and Design centres which are often remote from the operational world. Feedback, factual and fast is essential.

The post war period has brought about basic alterations in Dockyard production techniques. These have followed materials changes such as the introduction of aluminium bronze, with the increased emphasis upon greatly improved shock resistance and casting quality, requiring a re-appraisal of foundry standards and techniques, together with revised welding procedures, and the introduction of stainless steels with their wide ranges of composition and properties and limitations in certain environments. In the constructional sphere the change to steels of high yield point and improved low temperature impact properties has had a profound effect upon the Yard and a further important development is the increased use of light alloys in warship construction. These changes have required—and demand—an entirely new attitude from the pre-war period, when mild steel, machinery and tool steels, cast iron, gunmetal, brass, copper and white metal represented the basic materials of manufacture; the relatively large in-

built safety factor permitted by design when the "power/weight ratio" was not of the same importance as to-day, permitted the continuance of craft functions which had been handed down through the generations. Materials in general were usually capable of ready identification from their visual appearance or by simple tests. The metals of to-day are very varied and an almost identical appearance can be presented by alloys differing significantly in composition and properties.

A new language has emerged and the looseness of description tolerable in the past is no longer acceptable.

It is against this background that Dockyard science of the future must operate.

In the foregoing it has only been possible to review briefly the activities of the Devonport Laboratory. The scientific team has sought to establish a new attitude to Dockyard Science and to inspire a new relationship between the Laboratory and the other sections of the Dockyard in this vital field of Defence.

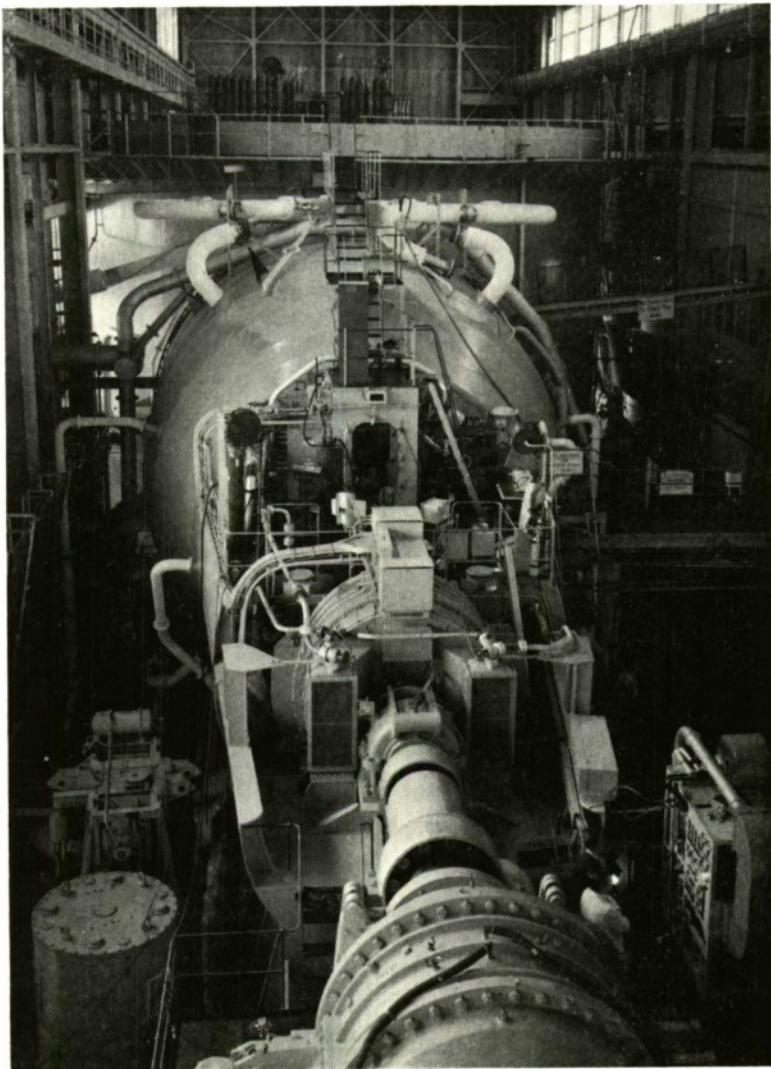
Despite their age the Dockyard Laboratories have only recently been recognised as important units for evaluating materials, new processes, and suggesting improvements in existing practices. They serve large manufacturing organisations and their geographic location enables them to "feel the pulse of the Fleet" in the materials sense. This source of contact between the R.N.S.S., the Production and Design Sections and the Fleet is vital to the future of the Royal Navy, and must become increasingly so as new technological advances are made. The close liaison established with the larger research establishments in the materials field is also seen as an urgent necessity if the many basic problems are to be properly enunciated and evaluated.

The results achieved, although significant, give no room at all for complacency, since so much remains to be done, but the nucleus of a modern dockyard scientific unit has been established and the progress achieved is consistent with the national trend and absolute need recognised at the highest national levels for a greatly increased scientific contribution in the industrial field.

It is to this end that the efforts of the scientific team in Devonport have been directed.

#### Acknowledgements

The author is greatly indebted to Captain J. G. Little, O.B.E., R.N., at whose instigation this article was prepared, and to Dr. C. D. Lawrence, O.B.E., Superintending Scientist of the Central Dockyard Laboratory, Portsmouth, for their support and encouragement without which the new concept of Dockyard Science in Devonport would not have been possible.



### R.N. NUCLEAR SUBMARINE PROTOTYPE PROPULSION PLANT

The Minister of Defence for the Royal Navy, Mr. Christopher Mayhew, M.P., visited the Admiralty Reactor Test Establishment at Dounreay, Caithness, on Friday, 2nd April. During his visit, he accepted the Dounreay submarine prototype from the main contractors, Messrs. Vickers-Armstrongs (Engineers) Ltd.

The prototype consists of a complete nuclear submarine propelling plant, in a truncated hull, erected on land and driving a brake. It has been undergoing extensive testing since the reactor first went critical on 7th January, 1965 and has been successfully operated at high power.

The other principal contractors involved in this major and novel project have been Messrs. Rolls Royce and Associates Ltd., Messrs. Foster Wheeler Ltd. and Messrs. Vickers-Armstrongs (Shipbuilders) Ltd. The prototype and site will be operated by Messrs. Rolls Royce and Associates Ltd. who will continue development of the prototype under the direction of the Ship Department of the Ministry of Defence (Navy).

The prototype will perform two principal functions, the development of nuclear submarine propulsion plant and training in machinery operation and maintenance for submarine crews.

The machinery is the forerunner of that fitted in the *Valiant* class submarines and the prototype has already proved exceedingly valuable in enabling the necessary design adjustments to be made in advance of the completion of the first vessel.

# SYMPOSIUM ON RADIOCHEMICAL METHODS OF ANALYSIS

Reported by D. W. Downton

Services Electronics Research Laboratory

This was the second such symposium sponsored by the International Atomic Energy Agency held in Europe. The title did not really reflect the subject matter covered since two-thirds of the papers presented come under the heading of radioactivation analysis. This is an important technique now for use by the analytical chemist but many would not agree that it deserved such a predominant place in radiochemical analysis.

The first day was taken up by techniques involving the use of a high level thermal neutron flux from a reactor and 14 papers were presented. J. P. W. Houtmann gave an interesting paper on the possibility of determining the age of paintings by the trace elements present and had done work on some 25 paintings made between 1510 and 1909. Forensic scientists have shown a great deal of interest in activation analysis since they so often deal with extremely small samples and this is shown by the number of papers on this subject, especially on the individualisation of hair, where work is proceeding in U.S., U.K., Brazil, Canada. I. W. Lima of Brazil outlined some of the problems but V. P. Guinn said there was still a lot of work to be done on this subject before any real conclusions could be drawn, but there have been at least two court cases in the U.S. during the last year where the results of activation analysis on microgram samples have been accepted as evidence.

The non-destructive nature of this form of analysis was emphasized by both Guinn and D. E. Fisher, of Cornell University, who described a method for analysis of meteorites. In this field inter-laboratory comparison of results *on the same specimen* of a given meteorite is important so that discrepancies due to inhomogeneities are minimised. Some of his latest results seem to show that the astro-physicists will have to change their present theories.

The use of fast neutrons for this form of analysis was recognised by the inclusion of a separate section of seven papers and D. E. Gibbons of Wantage Research Laboratory showed the use of 14 MeV neutrons for determination of barium, phosphorus, iron, sulphur and chlorine in lubricating oil. During discussion a short description was given of the sealed-off fast neutron/generator developed at S.E.R.L. The possibility of using such a tube for industrial purposes was welcomed and great interest aroused in any future developments giving higher outputs. S. S. Markowitz, Univer-

sity of California has used He-3 ions produced by a linear accelerator to detect oxygen and carbon and suggests that when the 12 in. cyclotron is available, determinations less than one part in  $10^9$  of oxygen carbon and other light elements will be detectable. He gave figures for Ge(Li) counters having an order of magnitude increase in resolution and work is proceeding to increase efficiencies.

The experimental techniques for use with activation analysis are continually becoming more sophisticated and F. Giradi of Euratom spoke of their progress towards automating the radiochemical separations. Three papers concerning spectrometry were presented. W. S. Lyon, Oak Ridge, gave a study of the errors encountered; R. W. Perkins, G.E.C., U.S.A., gave details of anti-coincidence shielded spectrometry and R. A. Dudley, I.A.E.A., commended stabilization with a feedback system. V. P. Guinn of G.A. San Diego, has pulsed a reactor having a normal output of  $7.8 \times 10^{12}$  n/cm<sup>2</sup>—sec so that it gives a 15 ms pulse of about  $4.5 \times 10^{14}$  n/cm<sup>2</sup>. This has enabled studies of short lived isotopes ( $\geq 0.05$  sec.) and determination to date of some 13 elements.

The second part of the Conference was concerned with applications of radioactive tracers. Budapest University has done a lot of work on radiometric titrations whilst medical workers use these techniques to determine iodine and vitamin B12.

The name "Kryptonates" has been applied to solids of all types into which krypton 85 has been incorporated, either by ion bombardment or diffusion. D. Chleck of Parametrics Inc., gave details of some interesting gas and solution analyses using this technique and using the kryptonates as an endpoint indicator in a volumetric titration.

Substoichiometric radioisotope dilution was introduced in 1961 by Ruzicka and there were two papers on the use of this method to determine trace amount of cobalt (by De Voe N.B.S.) and of iron by Ruzicka himself.

The last section of the symposium was taken up by papers on analysis by absorption, scattering and emission of radiation. X-ray fluorescence has been used to analyse iron, zinc and copper ores by T. Florkowski, Cracow; to determine tin by J. Rhodes, Wantage; and to analyse uranium solutions by S. Forsberg, Sweden. X-ray fluorescence is being used increasingly in industry and in the field of mining operations.

## CORRESPONDENCE

To The Editor,

*Journal of the Royal Naval Scientific Service*

Sir,

### The Human Preserve

Mr. Treacher is quite wrong in thinking that there will be "nobody to oil the robots." They will, of course, be oiled by other robots.

For the most lucid picture of a completely mechanised world and the fate of the bored human race, see *The Adventure of Wyndham Smith*, by that unjustly neglected author, S. Fowler Wright. However, Fowler Wright does prognosticate the ultimate triumph of the human spirit; I hope he's correct.

Yours faithfully,

S. Matthewman

## Notes and News

### Admiralty Experimental Works

A team from the Central Defence Staff visited A.E.W. on 19th February to familiarize themselves with the work of the establishment and discuss progress, while on 12th March, Dr. M. G. Whillans of the Canadian Joint Staff also paid a visit.

Recent major staff changes concerned the Chief Constructors: Mr. L. J. Brooks was promoted to Assistant Director of Naval Construction, and left at the end of February to take up a new appointment in Bath; Mr. F. H. J. Yearling became Deputy Superintendent in his place, with special responsibility for the Manoeuvring Tank; and Mr. M. Fisher joined A.E.W. on promotion to Chief Constructor on 1st March to take Mr. Yearling's place in charge of the Ship Tanks, Cavitation Tunnels and propeller work in general.



### Admiralty Materials Laboratory

The Defence Research Committee have approved that the Chief Scientist, Royal Navy, shall be responsible for the Ministry of Defence Fuel Cell Research Programme and that the Research Team should be located at A.M.L. and should work on behalf of all departments. The Team will form a part of the Chemical Engineering Division under Dr. R. G. H. Watson. Dr. Watson attended the National Fuel Cell Symposium in Paris during the last week in February at the invitation of the Delegation Generale a la Recherche Scientifique et Technique, where he presented a paper on the work in progress at A.M.L.

Mr. L. Kenworthy presented a paper entitled "Some Corrosion Problems in Naval Marine Engineering" to the Institute of Marine Engineers in London in January 1965, which was repeated to sections at Newcastle and Bath.

Dr. H. G. Stublings attended the Symposium on "Crustacea" organized by the Marine Biological Association of India at Ernakulam, Cochin, in January 1965, and also visited the Naval Chemical and Metallurgical Laboratory at Bombay, where he gave an address on "Biology in the Service of the Navy."

Mr. D. J. T. Tighe-Ford has returned to the Laboratory after a four months' tour of duty at the Naval Chemical and Metallurgical Laboratory at Bombay, which will be the subject of a future article in the Journal.

The following papers by members of the Laboratory staff have recently been published in the scientific and technical Press:—

"Some Observations on *Cladosporium resinae* as a Fuel Contaminant and its possible Role in the Corrosion of Aluminium Alloy Fuel Tanks." N. I. Hendey. *Trans. Brit. Mycol. Soc.*, 47 (1964) 467;

"P-Type delayed Fluorescence from Ionic Species and Aromatic Hydrocarbons." C. A. Parker, C. G. Hatchard and Thelma A. Joyce. *J. Mol. Spectroscopy*, 14 (1964) 311;

"Sensitized Delayed Fluorescence as an Analytical Method—Some Preliminary Experiments." C. A. Parker, C. G. Hatchard and Thelma A. Joyce. *The Analyst*, 90 (1965) 1.

The first Annual Exhibition of the Admiralty Materials Laboratory's Photographic Society was opened by its President, Dr. T. C. J. Ovenston, on 15th January, 1965, in the new canteen. He welcomed the Judge, Mr. S. F. James, F.I.B.P., and some 80 members and friends. The Exhibition attracted a large number of monochrome prints and colour slides, the general high standard of which was commented favourably upon by Mr. James. Cups were presented to Mr. A. J. Bloom for the "Slide of the Year" and to Mr. M. R. Bowditch for the "Print of the Year."



### Admiralty Surface Weapons Establishment

At a recent Conference at the Institution of Electrical Engineers, preliminary to a study of the fundamental processes used in designing electronic equipment, Mr. W. D. Mallinson reviewed the characteristics which are considered by a designer and suggested the different emphases for various user-environments, as well as the effect of various design-environments.

Mr. E. Searle embarked in H.M.S. *Eagle* at Devonport and took passage to Singapore for the purpose of observing the performance of the first Integrated Communications System fitted in the Fleet. Mr. A. G. Crocker visited Canada in March for discussions with the Royal Canadian Navy and Canadian contractors concerned with components of shipborne UHF communications equipment. Messrs. F. A. Kitchen, H. C. Gerry and L. Harrap visited the Netherlands recently for discussions with the Royal Netherlands Navy and Dutch contractors concerned with advanced shipborne HF communications and equipment. Mr. F. J. A. Scott of the establishment's Polaris Division is attending a ten week Course at Sperry's in New Jersey on the operation and maintenance of the latest Loran sea receiver.

Recent visitors to the establishment have included Messrs. B. Amsler, B. D. Dobbins and J. E. Hanson of the John Hopkins Applied Physics Laboratory, Captain

W. D. S. White, R.N. (Director of Weapons Programmes-Designate), Captain I. S. S. Mackay, R.N. (Assistant Director of Weapons Material-Designate), and Captain R. L. Clode, R.N. (Director of Weapons, Radio).

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#### Admiralty Underwater Weapons Establishment

It is with regret that we record the passing of George Frederick Mortimer, M.B.E., at his home, 234 Devonshire Avenue, Portsmouth, on 23rd March 1965; he was buried on the 29th March. Mr. Mortimer retired from the Royal Naval Scientific Service in March 1958 and an appreciation of his service was included in *J.R.N.S.S.*, 13 (March 1958). Until very recently he enjoyed good health and had an active life. He was a life-long member of the Salvation Army.

All his friends and colleagues extend to his widow and family their deepest sympathy.

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On 3rd February 1965, Dr. Benjamin, Chief Scientist, A.U.W.E., presented the Imperial Service Medal to Mr. F. C. Brake before a gathering of his colleagues. Mr. Brake, who was born in Weymouth in 1904, joined the Admiralty service at a fitter in 1933 and during World War II spent four years at the Royal Naval Torpedo Depot at Gibraltar. In June 1951, Mr. Brake was promoted to Laboratory Mechanic and he was disestablished and re-employed in October 1954.

Mr. Brake is a quiet and unassuming person, but a most conscientious and very loyal worker. He can always be relied upon to carry out any job given to him with little or no supervision and the Award of the Imperial Service Medal is well deserved.

#### Royal Naval Propellant Factory, Caerwent

An investigation has been carried out into the foreseeable requirements of the three Services for propellants and the production capacity for meeting these requirements. This has shown that the combined potential capacity of the Royal Naval Propellant Factory at Caerwent and the Royal Ordnance Factory at Bishopton is well in excess of any foreseeable need and that savings of £1M a year if not more would be obtained if production were concentrated in one factory.

It has therefore been decided to close the R.N.P.F. at Caerwent and to concentrate all future production at Bishopton. To ensure a smooth changeover the Caerwent Factory will need to remain in full production for at least another year and the run-down thereafter will need to be phased over about another two years. This will give time for full consultation with all interests concerned, including the Monmouthshire County Council as Local Planning Authority, about possible future uses of the site and for alternative employment to be sought for displaced workers.

The closure will ultimately affect about 1,300 industrial and 270 non-industrial staff. A small number of key staff will be transferred to Bishopton and established non-industrial staff for whom there are no vacancies at Bishopton will, where possible, be offered appropriate appointments elsewhere.

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#### Services Electronics Research Laboratory

During March last Mr. P. Gurnell paid a visit to Paris in connection with the Anglo-French exchange of information on semiconductors. Mr. M. E. Moncaster left the R.N.S.S. and S.E.R.L. on 19th March to take up an appointment with S.R.D.E. at Christchurch. Mr. R. K. Purohit, junior Scientific Officer of the Solid State Physics Laboratory, Delhi, arrived at S.E.R.L. on 24th March to spend a year working on compound semiconductors.

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#### Services Valve Test Laboratory

Mr. H. Lewis, the Officer-in-Charge, is to visit Tokyo from the 18th to 29th October 1965 where he will attend the International Electrotechnical Commission TC 39 Meetings.

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#### Senior Scientific Appointment

Mr. H. W. Pout has been promoted to Chief Scientific Officer and appointed as Assistant Chief Scientific Adviser (Projects) with effect from 1st April, 1965. Mr. Pout replaces Mr. E. C. Cornford who has already been appointed as Chief Scientist (Army).

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#### New Ocean Survey Ship for the Royal Navy

H.M.S. *Hecate*, second of the three deep ocean survey ships under construction for the Royal Navy, was launched at the Scotstoun, Glasgow, Ship Yard of Yarrow & Co. Ltd., on Wednesday, 31st March. The ships which are intended for a combined oceanographical and hydrographical role were ordered from Yarrow & Co. Ltd. in February of last year and the first vessel, H.M.S. *Hecla*, was launched in December last by Messrs. Blyths Wood Shipbuilding Co. Ltd., of Scotstoun, who are collaborating in work on two of the hulls.

The *Hecate* and her sisterships have an overall length of 260 ft., a beam measurement of 49 ft. and a draught of 15 ft. They will have a displacement of 2,800 tons and be capable of 14 knots with a range of 12,000 miles.

## Measurement of Residual Stresses

On the afternoon of 3rd March some 65 people attended a meeting under the Chairmanship of Professor J. M. Alexander of the Imperial College of Science and Technology on the Measurement of Residual Stresses arranged by the Institute of Welding on behalf of the Joint British Committee for Stress Analysis. The meeting consisted chiefly of a series of short lectures summarising the work done by various speakers and covering a wide range of applications from mining to welding and of materials from rock to metal. Amongst the list of contributions were the following:

"The Significance of Residual Stress" by Mr. G. M. Boyd (Lloyd's Register of Shipping) who emphasized the importance of deciding whether or not residual stresses were of importance in any particular case. In welded joints, residual stresses are always found up to yield point because they are induced by plastic flow; they can be relieved by a small plastic strain (0.13% in case of steel) and if the material can accommodate this order of strain without fracture, residual stresses are of little significance in terms of mechanical strength. However, they are of importance, Mr. Boyd said, if the material is brittle and when, for example, stress corrosion and machining stability are criteria. He explained that the so-called relief treatment was often a misnomer as the beneficial metallurgical changes caused by the treatment were very often the most important effect. Mr. Boyd further stressed that an important point to remember is that determinations of residual stresses are confined to the measurement of elastic strains and that they do not reveal the extent of previous plastic flow. Mr. J. R. Dickson of the National Engineering Laboratory in his paper, "Residual Stresses around Cracks," explained the technique of fringe pattern photoelastic measurement in which the plastic coating used acted as an infinite number of strain gauges. He showed the application of the method to the determination of the residual stress field around the ends of a growing fatigue crack. The prediction of the stresses and strains by continuum mechanics methods was found to give good correlation with the experimental data. An interferometer technique was used by Mr. A. A. Denton of the Imperial College of Science and Technology who, in his paper, "The Effect of Layer Removal Technique on the Accuracy of Residual Stress Determination," described the method to determine the residual stresses in  $\frac{1}{4}$  in. sheet over a length of 0.1 in. throughout the thickness of the material, providing an estimated accuracy of  $\pm 1,000$  lbs. per square inch. Stresses at different depths were measured by Mr. Denton by layer removal and, following a study of possible methods, spark erosion had been found to be the most satisfactory. Mr. Denton considered that this system has several advantages over acid etch and machining but considerable residual stresses are induced by the mechanism of metal removal. However, the residual stress pattern is very consistent for given parameters of the equipment and calibration on annealed material is therefore possible.

The importance of understanding the significance of residual stresses at the design stage was emphasized by

Mr. D. W. Smith of the Ministry of Aviation in his paper entitled "Residual Stress Measurement by Strain Relaxation Methods," in which he stressed the value of feeding back experience of service performance to the design department. Three examples were quoted to illustrate his theme—the failure of a hydraulic component under test at a nominal 7 tons per square inch in which the residual stress at the point of failure was found to be 18 tons per square inch; weld cracking in a complex fabrication of extruded sections; failure of explosively driven pins attaching glass fibre panels to triangular steel frames in a large structure. In this last case 12,000 pins had failed. Mr. Smith was of the opinion that the strain relaxation method using resistance strain gauges was a useful and practical inspection technique in several fields of process control. Dr. G. Forrest of Aluminium Laboratories Ltd., in his paper, "Some Experience of the Measurement of Residual Stresses in Aluminium Alloys," showed three examples of residual stress measurement. The first concerned a cast cylindrical aluminium billet, the stresses being determined by the Sach's "boring out" method. The point was made that where high triple tensile stresses occurred at the centre, elastic deformation following the boring operation could not be assumed, and the normal analysis could be in error. The second concerned stresses in a formed channel section, and showed a comparison of results of experimental measurement with calculation from the stress/strain curve of the material. The third example, on thin plate, showed that considerable distortion could result from machining processes. The X-ray back-reflection technique was explained by Mr. E. A. Fell, of High Duty Alloys Ltd. The method depends on the differences in interatomic spacing between planes of atoms at different stress levels. The reflection pattern provides a means of estimating the stress present in a surface layer about 0.003 in. thick but it is sensitive to crystal orientation; this is a critical factor in certain materials such as nickel alloys. Experiments to compare the X-ray system with strain gauge measurements show good correlation and work on an undercarriage leg showed the limitations of strain gauges. It was interesting to note that the X-ray technique was capable of measuring residual stresses in sections as small as  $\frac{1}{2}$  in. x  $\frac{1}{2}$  in. x  $\frac{1}{2}$  in. removed from the component.

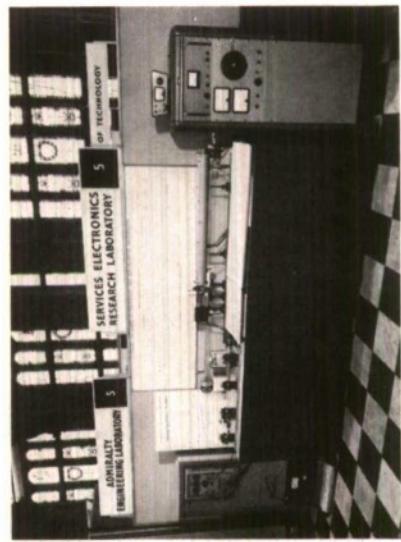
A technique in use at British Welding Research Association was outlined by Mr. Dawes in which the strain is measured by an extensometer located across the gauge length on steel balls pressed into the metal surface. An accuracy of 0.6 tons per square inch is claimed. Mr. Dawes showed the use of the system for measuring residual strains during the prefabrication of a component.

Other papers presented to the meeting were as follows:

"Existing Stresses in Stonework and Brickwork," by Mr. R. S. Jerrett of the Building Research Station; "Stress Changes Remote from Underground Mine Opening," by Mr. N. Tomlin, University of Newcastle-upon-Tyne; "Residual Stresses in Piles and Pile Groups," by Mr. R. W. Cooke of Building Research Station; and "Notes on Work Overseas," by Dr. J. F. Alder of the Fighting Vehicles Research and Development Establishment.



A.E.L. Point impedance graphical plotter system.



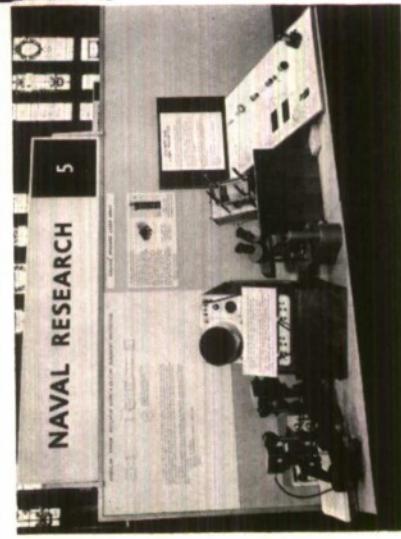
S.E.R.I. Pulsed Gas Lasers.



S.E.R.I. Angular error indicator, GaAs Laser array and 100 W GaAs Transmitter.



A.S.W.E. Incremental Computer.



S.E.R.I. GaAs Laser Altimeter and Rangefinder.

*Views of the Naval Research stand at the Exhibition of Scientific Instruments, sponsored by the Institute of Physics and the Physical Society, at Manchester, April 5-8 1965.*

# Book Reviews

**An Introduction to Dimensional Method.** By E. W. Jupp.  
Pp. 89. London; Cleaver-Hume Press Ltd. 1962.  
Price 12s. 6d.

Unlike some text-books which sacrifice clarity for the sake of brevity, this book is the essence of simplicity throughout. In fact, in the opinion of the reviewer the simplicity is somewhat overdone: "proving" that the area of a square depends on the square of a characteristic length, or that the volume of a sphere is proportional to the cube of the radius appears to be begging the question, however much one might waffle on about indicial equations.

Chapter one contains a general discussion on the philosophy of measurement and introduces one to the idea of dimensions. In this chapter, as elsewhere, the author is telling us what we already know perfectly well, but one derives a certain satisfaction in seeing it stated formally. Chapter Two enumerates and discusses various systems of units in common use, and deals with conversion from one to another.

Chapters three and four form the basis of the book, covering dimensional homogeneity, dimensionless products and in general how to find the form of relationships between variables in a problem. This section in particular has many worked examples to demonstrate clearly the methods involved.

Chapter five deals with the theory of models and discusses the various restrictions which must be placed on a model in order to stimulate the full-scale problem. Dimensional analysis is used to derive these restrictions, but the author fails to bring out the point that much experimental work can be avoided by using the theory of dimensions to effectively reduce the number of variables in a problem. For example, the drag on a body moving in a viscous fluid can be expressed in terms of two numbers (the pressure coefficient and Reynold's number) instead of five.

Chapter six covers general experimental method, and deals with extracting the maximum information from experimental results, the minimisation of errors, and planning of experiments. Such a chapter seems somewhat out of place in such a small book—a student searching for such information would normally look elsewhere. Chapter seven lists some dimensionless products much used in fluid mechanics, with a note on the applicability of each. Chapter eight contains a short bibliography in the field of dimensional analysis.

On the whole the book fulfils its purpose (criticisms are of style rather than content) but it is difficult to guess for whom the book is intended. The presentation is suitable for school use, but the illustrative problems, mainly in fluid mechanics, would not be familiar in such a context. To anyone with a gap in his formal education, this book might be useful, but the price (12s. 6d. for 89 pages) may prove prohibitive.

I. McPherson

**The Mechanical Properties of Matter.** By A. H. Cottrell.  
Pp. x + 430. New York, London and Sydney; John Wiley and Sons Inc. 1964. Price 70s.

If an author is to write a book with a title such as "The Mechanical Properties of Matter" he must either give a new and improved presentation of old material, or produce a wealth of new material which has not been included in the many previous books of similar title, Professor Cottrell has attempted to satisfy both of these counts.

The book is intended for use by first or second year university students. However, the rather elementary mathematical treatment of the subject matter may, to some extent, defeat this aim. Throughout the book the treatment of the various topics is based on an atomistic view of matter. Some subjects, such as the properties of gases and the structure of crystals, are obviously suited to such a treatment. Other subjects such as gravitation, which are usually included in books with the similar but wider title "The General Properties of Matter" find no place in this volume. To this extent the book cuts across traditional subject boundaries and, while this is in many ways a good thing, it may be an annoyance to some readers.

The book contains twelve chapters covering such topics as perfect gases, elasticity, fluidity and viscosity, surfaces, fracture of solids and fluid mechanics. One or two chapters will be considered in some detail as this will serve to illustrate the scope and level of the book.

The chapter on perfect gases illustrates well the possible scope of the atomistic approach since most of the properties of an ideal gas can be derived in some detail by considering a gas as a collection of elastic particles. However, the chapter includes nothing which will not be found in any of the standard text books on heat and thermodynamics. Also included in this chapter is a list of the physical properties of the elements; this would be better included as an appendix. It would also be better if a more consistent set of units was used for the physical properties given. For example, units used in the table include  $^{\circ}\text{C}$  (boiling point),  $0.1 \text{ cal g}^{-1} \text{ }^{\circ}\text{C}^{-1}$  (specific heat) and  $10^6 \text{ p.s.i.}$  (Young's modulus).

In the chapter entitled "Elasticity" the elastic properties of a crystal are related to its structure and the forces between the constituent atoms. However, for many materials this is not a practical approach and the usual definitions of stress and strain and the experimentally determined elastic moduli must be considered. Accordingly, an excellent elementary treatment of the generalised concepts of stress and strain is given. The following chapter deals with practical problems in elasticity such as the bending of beams and the torsion of cylinders and there is an interesting section on dislocation and cracks.

The great value of this book lies in such chapters as those dealing with plastic crystals and plasticity. These chapters contain a wide range of material which is not readily available in elementary books. The chapter on plastic crystals considers the motion of dislocations through crystals and its effect on the hardness of materials while the following chapter ranges from soil mechanics to deformation by creep.

Professor Cottrell has written a very lucid and readable elementary account of the mechanical properties of matter. Although not a complete text book it should be of value to all science and engineering students and will provide practicing scientists with a good introductory account of some unfamiliar subjects.

C. H. Gooch

**Introduction to Elasticity.** By G. Nadeau. Pp. xii+285. New York and London; Holt, Reinehart and Winston, Inc., 1964. Price 56s.

The author states that this book is written primarily for undergraduates in physics, and to promote the use of dyadics in teaching elasticity. After an introductory chapter defining dyadics and operations on them, the three parts of the book are devoted to the general linear theory for isotropic bodies and infinitesimal strains, to problems in static elasticity and to wave motions. Any elasticity book of this size must give problems from selected topics only; here the static ones are those whose stress functions are simple combinations of elementary standard forms, with a leaning towards those in cylindrical co-ordinates. The treatment of torsion and flexure is the most extensive, and that of plane problems brief. The speciality of the book is its group of chapters on waves, the motion of an unbounded body with various symmetries, at an interface and the vibrations of finite bodies.

The advantages of the use of dyadics should be the same as those of vectors. Firstly clarity, as each step of analysis should have a physical as well as a mathematical meaning; and secondly economy in writing, for the memory, and in using only a small number of operations, each with an explicit purpose. Applied to elasticity, the nature of dyadics is a description of properties of strain and stress, and it is a weakness in this book that the growth of the dyadics out of these properties is not shown. Thus for stress, the reader is left to take it on trust that the variation of the stress across an element of area with its orientation is as for a dyadic; there is silence as to the dynamical reason. Instead, the introduction catalogues the possible operations without illustrating their purpose.

The fundamental equations exhibit the advantages of the approach, as, in general, do their derivations. In particular problems, many procedures look cumbrous, yet one is often enabled to see the state of stress as a unity.

The writing is clear, yet a few obscurities occur. In plane strain, a cylinder with generators parallel to Oz is under forces with no z component and independent of z; therefore, it is said, the displacement is independent of z and  $w = 0$ ; but the context later corrects this. Again, the stress energy appears to involve isothermal deformations in which no heat is produced.

Such points are rare, and the book remains a good text within the field considered.

**R. B. Harvey**

**Introductory Electricity and Atomic Physics.** By J. Yarwood and K. J. Close. Pp. xiv + 743. London; Longmans, Green and Co, Ltd., 1964. Price 30s.

This book gives a very thorough account of Electricity, Magnetism and Atomic Physics to the standard demanded by the G.C.E. 'A' level examination including the Special paper. It is also an extremely useful book for students reading Physics in their first year at University.

The authors have departed to a certain extent from the traditional approach to Electricity and Magnetism, in favour of more modern ideas. For instance, although topics such as the bar magnet, gold leaf electroscope and tangent galvanometer are included, they occupy less space than they would in an older text book. More prominence is given to the simple principles of modern instrumentation and topics such as the valve voltmeter, cathode ray oscilloscope and electrometer valve are discussed.

The general layout of the book is pleasing and the chapters follow in a logical sequence. Chapter 1 gives an elementary introduction to the structure of matter, and this is particularly useful because it helps to unify some of the apparently disconnected topics encountered later

on. Chapters 2-19 then cover in a very clear and quite detailed manner, all the material usually found in a book of this nature. Topics such as Electrostatics, Direct Currents, the Potentiometer, Wheatstone Bridge, Magnetic Properties of Materials, Thermoelectricity and many others all have at least one chapter devoted to them. Worthy of a special mention is the 83-page chapter on Vacuum Tube Electronics which includes descriptions of the Valve oscillator, a simple Radio Transmitter and the principles of Radio Communication.

The last section of the book deals with "Atomic Physics" and includes chapters on the Periodic Table, X-rays, Nuclear Physics and Semiconductors. It is this section in particular which will be of the greatest use to the more advanced student. The electronic structure of atoms, Bohr Theory of the hydrogen atom, quantum numbers and the Pauli exclusion principle are covered in some detail in Chapter 20. Chapter 21 deals with X-rays in both theory and practise. Continuous and characteristic spectra are discussed as well as X-ray diffraction and its application to the determination of crystal structures. Chapter 22 gives a 50-page account of nuclear physics including radio-activity. Topics discussed include the Mass spectrograph, isotopes and nuclides, transmutation of elements and thermonuclear reactions. In the last chapter the principles of both intrinsic and extrinsic semiconductors are described and the theory of the p-n junction is given.

This book contains a large number of both worked and unworked examples and all answers are tabulated. The reader will require an elementary knowledge of the Calculus in order to follow some of the proofs. However it is an excellent text, well illustrated, and must surely be of great benefit to future students of Physics.

**R. G. F. Taylor**

**Stress Analysis and Vibrations of Elastic Bodies.** By T. V. Duggan. Pp. viii + 588. London; Temple Press Books Ltd., 1964. Price 105s.

This book covers in one volume, the two subjects of strength of materials and mechanical vibrations. As the author states, it is unique in dealing with both subjects in parallel. Although written primarily for design engineers, it covers much of the work necessary for degree and diploma courses, especially the Diploma in Technology. The text is comprehensive in its coverage, and sufficiently clear to enable the unsupervised student to use it effectively. However an elementary knowledge of the Calculus is necessary before reading the book. Particular attention is paid to the more practical methods of solution so that the reader is supplied with sufficient knowledge to apply his theory to design problems. Strain energy methods are used extensively for solving the majority of statically indeterminate problems.

The text begins with chapters covering the basic ideas of stress and strain, bending moments and shearing forces. These are followed by the theories of bending and torsion and an introduction to mechanical vibrations. The theory of columns and struts, shafts of non-constant flexure and the theory of disks and cylinders are dealt with lucidly. There is also a very instructive chapter on forced and damped vibrations and the final chapter gives an introduction to Plasticity. Three appendices follow and they deal in turn with Properties of Areas and Rotating Bodies, General Theorems of Strain Energy and Stress Concentration Design Factors.

The whole book is very well illustrated with over 100 diagrams. The text contains numerous worked examples and at the end of each chapter there is a comprehensive bibliography. There are also plenty of unworked examples taken from past examination papers. This book should be of considerable value to all students of engineering

and physics. The chapters follow in a logical sequence and the two fundamental topics have been interwoven very successfully.

I would mention, however, that the book deals only with macroscopic phenomena. No mention is made, for instance, as to why metals have a yield point, and the incremental nature of plastic deformation is not brought out at all. An additional chapter or appendix, covering elementary dislocation theory would enable the student to have a greater basic understanding of the strength of materials.

R. G. F. Taylor

**Electromagnetic Theory for Engineering Applications.** By W. L. Weeks. Pp. 744. New York; London; Sydney. John Wiley & Sons Inc. 1964. Price 135s.

Many excellent books have been written on electromagnetic theory and its application to engineering, but Professor Weeks' book approaches the subject from a somewhat unusual angle: instead of following the established procedure of beginning with electro- and magnetostatics, this book starts with a statement of Maxwell's equations, and then proceeds to develop the whole edifice of electromagnetism in a systematic and very concise way. A rigorous treatment is given in terms of vector analysis and calculus, a full knowledge of which is presumed. Post-graduate students in their first year should be able to follow the development in detail.

After an introductory survey the theory of electromagnetic fields is developed in detail and is then applied to the simplest one-dimensional case, the transmission line. Discrete current and voltage sources are included in the general field equations without affecting their fundamental simplicity and elegance. This is done by means of delta-functions, operative in space as well as in time. The use of Greens' functions is described, which form a powerful tool when dealing not only with point sources but also with those of finite dimensions. The discussion of a transmission line with periodic discontinuities, e.g. resistive, capacitive and inductive loads, neatly illustrates how a complex problem such as Brillouin zones in periodic three-dimensional structures, can be introduced in easy stages: the treatment of the one-dimensional case readily leads to the familiar concept of low-pass filters and to their analogue, the discrete energy bands in solid crystals.

There is an extensive chapter dealing with general methods for the solution of the differential equations occurring in electromagnetic theory. Amongst these the reciprocity theorem, and the equivalence theorem (Huyghens principle) are shown to be of great potential use in the solution of special field problems. Several chapters on two- and three-dimensional problems form the latter half of the book dealing with the solution of fields in rectangular, cylindrical and spherical co-ordinate systems, with particular emphasis on waveguides and cavities, antenna systems and radiation into, and propagation in, free space. The final chapter deals with field mapping and with transient fields.

Each of the eight chapters is followed by a set of problems—real problems such as often face the professional engineer. A summary of about 30 pages at the end of the book recapitulates briefly the essential results of each chapter. A comprehensive list of notations and a detailed subject index conclude the book. The production of text and figures alike is excellent.

To this reviewer this is an almost ideal book in every respect and can be highly recommended to serious students.

E. Billig

**Elements of Feedback and Control.** By A. M. Hardie. Pp. xi + 344. London; Oxford University Press. 1964. Price 55s. (in U.K. only).

The main bulk of this book is concerned with the basic principles of servo control systems treated in very simple fashion. Whilst the complex plane and the encirclement theorem are introduced there is only a brief treatment of the theory of functions of a complex variable. The author has therefore chosen to omit Laplace transforms, the Routh-Hurwitz criteria, the inverse Nyquist locus, root-locus methods and M circles. A large proportion of the book is devoted to the properties of systems whose performances are given by the solutions of second order differential equations with constant coefficients. Worked examples given to clarify each stage of the reasoning are well chosen and should prove valuable to the student who follows them through with pencil and paper. A number of exercises is also provided on the contents of the six middle chapters which are more analytical than descriptive. Answers to these are given at the end of the book.

The first two chapters serve to introduce the concepts of feedback and feedback control systems. Also included are simple explanations and mathematical treatments of the dynamics of the mechanical and analogous electrical principles and quantities involved in the study of the subject. A most misleading error appears in Fig. 15 (b) which shows a graph of the phase characteristics of a simple electrical system or of its mechanical analogue. It incorrectly implies a phase change of 180 degrees at  $\omega_n$  whereas the polar plot of the phase and gain characteristics of the same system shown in Fig. 19 is correct.

System performance analysis with feedback applied is introduced in the third chapter where some characteristics of mechanical and electrical position control systems, the effects of varying certain system parameters and of elimination of the steady state error are briefly examined. The properties of electric servo motors where they affect feedback control system performances are also examined at this stage.

The fourth chapter which comprises nearly 20% of the book is devoted to a study of negative feedback amplifiers and their similarity to the control systems studied previously. It primarily concerns electronic valve amplifier circuitry. Although no reference is made to transistors the principles given have universal application.

Except for the last chapter the remainder of the book is mainly concerned with the prediction of system stability and performance. It commences with detailed examinations of some of the well known methods of improving performance, followed by a commendably clear treatment of the more straightforward methods of stability analysis and calculation. The author then passes on to the consideration of transfer functions and their uses and stability analysis from logarithmic phase and gain characteristics by Bode's method.

To complete the book the author gives descriptions of the operation of some components common to many electrical, mechanical or hydraulic systems, together with brief mathematical treatments of the performances of some of them.

In reading this book it soon becomes evident that Mr. Hardie is a very experienced lecturer in the subject. He is well aware of the difficulties encountered by students and has taken extra care in his explanations of the more subtle and the critical points. The book should prove useful to students new to the subject as a class textbook and to those who by private study wish to acquire a basic knowledge of the subject.

J. W. Hargreaves

**General Science: Chemistry.** By C. W. Wood. Pp. 179. London; Pergamon Press, 1963. Price 12s. 6d.

Nowadays, straight chemistry seems almost as old hat as TW.3. But the late Mr. Wood has managed to produce a lucid, concise and even attractive book about the very basics of the subject up to G.C.E. General Sciences I level. The 50 or so black and white figures are clear and the whole printing effort and layout is well up to Pergamon's own superlative standard (except for a murky photograph of Aladdin's Cave).

I had not thought to find in this little book any matters of sufficiently great import to tax the brains of readers of these pages; but rather a handy reference book for those disarming, throwaway homework questions that bother one so after a hard day's work as they come winging their way across the supper table. You know the sort of thing:

Daddy, do nitrites come before nitrates in the nitrogen cycle or versa vica? Is soap a detergent? Who was Bécquerel? What does brimstone mean? Sketch and/or describe Xylene, an allotrope, oxyhaemoglobin, or hydronium.

This book will give you all the answers and many more. If one of your nearest is sitting his G.C.E. this year or if you think that Kipp's apparatus is a new model of electric blanket, then you need this book now.

M. V. Worstell

**Liquid Fuels.** By D. A. Williams and G. Jones. Pp. viii + 178. Oxford; Pergamon Press; New York, the Macmillan Company. 1963. Price 21s.

There is a growing trend to present technical books in paper cover form, with obvious cost advantages. "Liquid Fuels" is an excellent example, being printed on good quality paper with a clear type and durable covers, yet still costing only 21s. The range of material, with copious references, makes this a book for student, lecturer and practising engineer.

The presentation of material is in logical order. The early chapters cover the manufacture of liquid fuels from petroleum, oil shale and coal. Simple flow diagrams are included for distillation, reforming and subsidiary processes without clogging the text with petty detail. Adequate references are given for extended study. Properties of liquid fuels are next covered, defining the properties and indicating their usefulness. The first chapters to deal with specialised application of liquid fuels cover internal combustion engines. Combustion abnormalities are discussed with the relevant fuel properties, tests and specifications.

Before discussing the larger industrial applications of liquid fuels, a chapter is devoted to the methods available for fuel atomisation and the uses appropriate to each method. The chapter closes with a few paragraphs on combustion efficiency and corrosion control. The industrial applications chapters cover boilers, furnaces, turbines and gas manufacture. Diagrammatic sketches, flow sheets and occasional photographs are used to good effect and the text is devoid of excess detail. Principles and practice are discussed in each section.

A chapter is devoted to the rapidly expanding domestic heating field. This covers space heaters, combustion equipment for central heating, boilers and controls, again using diagrammatic sketches and cutaway drawings.

The final chapter covers the storage and handling of liquid fuels, dealing with all types from liquefied petroleum gas to heavy fuel oils. Handling, in this instance, means transport, putting into and taking out of storage and delivery to the combustion equipment.

At the end of each chapter is given a list of references appropriate to the topic of that chapter. The references are adequate for normal requirements.

Faults of this book are few and of a minor nature. Printing errors are rare and it is unfortunate that one should occur in a chapter heading. Depth of detail, though never obtrusive, does vary. For example, the detail given for diesel engine cycle and practice considerably exceeds that given for the spark ignition engine. With respect to the introduction to spark ignition engine combustion, it must be stressed that there is a distinct difference between "pinking" and "knocking," a difference which is apparently not appreciated. The chapter on gas manufacture is out of date. It is no author fault—just the speed of developments outstripping the technical reference books.

These are small criticisms and in no way detract from the value of this work. I feel that this book, at this price, must become very popular.

M. E. Horsley

**Fisheries Investigations, Series IV. An introductory Account of the Smaller Algae of British Coastal Waters. Part V: Bacillariophyceae (Diatoms).** By N. Ingram Hendey. Ministry of Agriculture, Fisheries and Food. Pp. i-xii, 1-317, text figs. 1-9, pls. I-XLV. H.M. Stationery Office. 1964. Price 180s.

It is hardly possible to do full justice to a work on this scale, involving the author's lifetime's experience and the bulk of his effort over the last 10 years, in any short review. Since it seems to the writer to succeed most admirably in its aims, the attempt should be made, if only to encourage anyone in anyway concerned with the subject to consult it.

The price may seem high, but it is not really so when one considers that on the 35 well arranged plates there are some 180 original drawings, 320 micro-photographs and 11 electron micrographs, all beautifully reproduced. The standard of the few text figures is also high, the type and format excellent. The degree of freedom from typographical error is quite remarkable in a work of this kind, and underlines the author's acknowledgments to the preliminary editing of Miss Bedford of the Ministry's staff at Lowestoft.

The only possible improvement in detail one could suggest would be that magnification figures were quoted after the legends on the pages facing the plates, since these will be in very frequent use. It is difficult even for trained biologists if they lack previous close acquaintance with this group of Algae, to appreciate the size difference of the numerous species properly without this aid. Since however, the size-range for each species is given in the text, the point is of small moment. The drawings of the planktonic species, which are less amenable to microphotography than the more heavily silicified sessile forms, are particularly good.

The taxonomic descriptions are very well done, and it should be noted that while some may find Hendey's classificatory system a drastic divergence from earlier ones, the terminology employed conforms strictly to Art. 35 of the International Code of Botanical Nomenclature (Utrecht, 1952).

With the illustrations, systematics occupies three-quarters of the whole book. This is inevitable because the provision of full means of identification for each one of the six hundred species dealt with was one of the author's main objectives. But the work as a whole is planned to do much more than this "... to produce for use in Fisheries Laboratories an account of the life-history, reproduction, classification and distribution of the more frequently occurring diatoms to be found in the open sea, in coastal waters, in estuaries and on mudflats

or salt-marshes round the coasts of Britain." Accordingly we find the shorter early chapters on such topics as methods, movements, distribution and ecology at least as valuable as the systematics. Each provides a reasonably up-to-date synopsis of "the present state of knowledge" of the several topics dealt with, and could provide a sound basis for detailed "synthesis" if full use were also made of the well-selected bibliography. Thus the book should be of great value to all marine biologists, not only the workers on fishery problems. It is moreover so well-written that the first year student or amateur microscopist should be able to use it, as well as those who will find it a good guide in more advanced studies.

One valuable feature is adequate definition, well illustrated, of the various "shape-forms" used in formal taxonomic descriptions of diatoms; words like "arcuate" "cuneate," "gonioid," etc. Some of these are sufficiently self-explanatory to obviate the need for definition, but others are obscure to all but the specialists, and the matter has too often been neglected in previous general works on the group.

The short account of the ecology of the littoral and sessile forms is particularly useful because much of the best work on these, including some of the author's, is so recent that it had not previously "got into the textbooks." The bottom forms have hitherto been far less thoroughly investigated than the planktonic ones, whose distribution and ecology is of such obvious importance in fisheries work, owing to their position at the base of the food-chains. Thus while many pioneers of fisheries biology have studied these problems concerning planktonic diatoms, the ecological importance of the littoral and sessile populations is only just beginning to be properly appreciated. Their habitus is very restricted spatially, but much more varied—we find they present a vastly greater diversity of species—and within their limits it is rapidly becoming apparent that their ecological significance may be very great. No "synthesis" of this work has yet been made, but the author provides a brief résumé that could well serve as the basis for such a study, presented as though he were striving to give the next man a flying start, perhaps, indeed the ideal motivation for all such work. We must all hope that Mr. Hendey will himself continue to help carry this particular torch far beyond Mexico.

T. J. Hart

**The Official View of Education.** By J. Letto. Pp. xiii + 143. Oxford; Pergamon Press; New York; The Macmillan Company. 1964. Price 12s. 6d.

The Pergamon Press has recently inaugurated an ambitious series of paperbacks on serious technical subjects, divided into a number of groups; the present volume is the first in the division devoted to educational research.

The title of the book is a little surprising as it contains very little of official views; the sub-title "A summary of the major educational reports since 1944" is in fact descriptive of the contents though the introduction deals with the Hadow, Spens and Norwood reports before that date and, briefly, with the 1944 Education Act.

The body of the book has little about primary education and quite a lot about some subjects which might not, *prima facie*, be thought of as education, such as youth service and social services. The treatment is to give factual summaries of the successive reports which have been issued in the several fields, of the comments which were made on them and of the action which was taken, and in all this the official views are only given briefly, if at all, and then not particularly sympathetically.

It may, of course, be said that the reports are themselves expressions of official views, but this would not hold water: they were drawn up by independent committees and they formed official views rather than reflected them. In fact the book is in the main studiously factual and Mr. Letto does not let his views obtrude any more than the official ones. He does here and there seem a little confused about points of procedure but the book gives admirably clear summaries of the reports and in an appendix the terms of reference and other information about the committees which were responsible for them.

If the allocation of reports to the chapters on secondary education, technical, agricultural and commercial education, further education and higher education sometimes seems a little arbitrary it is largely because some of the reports deal with a range of subjects, and if the sequence of the chapters is not easy to follow, then this is unlikely to confuse the reader or to make it difficult to find a particular report, although there is no index and the appendix already mentioned does not give the pages on which the reports are summarised.

The book is likely to be invaluable to anyone who has an interest in post-primary education, a subject in which the names of reports are bandied about in a way that sometimes seems calculated to display one's own experience and test that of others, but it would be unfair to suggest that it would be used as a tool with which to "blind with science": it enables the reader to follow the various strains which have characterised educational thinking since the last war without attempting to impress a thesis upon him and it is very good value for money.

A. E. Holloway

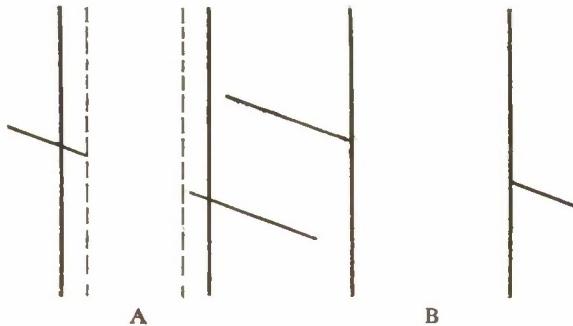
**Optical Illusions.** By S. Tolansky. Pp. ix + 157. Oxford; Pergamon Press. 1964. Price 35s.

This little book is written primarily for a popular audience although it repeatedly emphasizes how optical illusions can affect scientific observations, especially in the author's field of crystallography, and it is not only of interest and diversion to the general reader, but also of instruction to the scientist.

The illusions described are grouped together as far as possible, though some of them defy classification and others combine two or more principles, and they are covered by commentaries as well as descriptions, illustrating the circumstances in which they may be encountered. This sometimes results in a rather inflated amount of letterpress about a familiar effect, and this is particularly the case in the chapter on the size of the moon in art where four examples are extended to 18 pages; in the same chapter El Greco's distortions are discussed and their attribution to the artist's astigmatism cogently dismissed as untenable.

The 80 figures well illustrate the effects they display, but it is noticeable that to some readers at least some of the illusions are more or less impressive than they are to Professor Tolansky. This seems to be due not to astigmatism, the influence of which is briefly discussed, but to the mental interpretation of what the eyes see.

It is rather surprising that Professor Tolansky is unable to account for the Poggendorff illusion, for the explanation seems not to be difficult. If one is looking at a broad vertical bar behind which a thin straight oblique wire passes, as in diagram A, the left eye sees the left-hand side of the bar and wire from a slightly "round the corner" position, so that the wire appears to continue on to X before it disappears behind the bar; similarly the right eye sees the right-hand side of the wire appear to continue on to Y, and the two eyes produce a composite image, as in diagram B. Since this is what we are accustomed to see the brain rationalises, as in diagram B, to



show a straight continuous wire although examination shows that it does nothing of the sort, and consequently diagram A is interpreted as showing a broken wire. There is an error in the description of Fig. 40, showing a variation of Poggendorff's illusion, the true line being the bottom alternative, and not the one above it, as stated.

The book is well produced and covers a good range of effects, though it is by no means comprehensive; it gives a well considered account of a series of effects which are sufficiently remarkable and familiar to have attracted a good deal of attention in the past but which have been by comparison neglected for a number of years, but its price is likely to restrict its public to the libraries and the comparative few whose interest has already been aroused.

A. H. Holloway



## Books received for Review

Offers to review should be addressed to the Editor.

### The Future of Fuel Technology.

Edited by G. N. Critchley.

Pergamon Press Ltd. 1964. Price 70s. (No. 1311).

### The Theory of Order-Disorder in Alloys.

M. A. Krivoglaz.

Macdonald & Co. (Publishers) Ltd. 1965. Price 90s. (No. 1314).

### Structure of Atomic Nuclei.

C. Sharpe Cooke.

D. Van Nostrand Co. Ltd. 1965. Price 12s. (No. 1315).

### An Introduction to the Special Theory of Relativity.

R. Katz.

D. Van Nostrand Co. Ltd. 1965. Price 12s. (No. 1316).

### Temperatures very Low and very High.

M. W. Zemansky.

D. Van Nostrand Co. Ltd. 1965. Price 12s. (No. 1317).

### Polarized Light.

W. A. Shurcliff.

D. Van Nostrand Co. Ltd. 1965. Price 12s. (No. 1318).

### Essentials of Electricity and Magnetism.

O. M. White.

Macmillan & Co. Ltd. 1965. Price 20s. (No. 1319).

### Essentials of Heat.

O. M. White.

Macmillan & Co. Ltd. 1965. Price 15s. (1320).

### Maintainability, A Major Element of System Effectiveness.

A. S. Goldman and T. B. Slattery.

J. Wiley & Sons Ltd. 1965. Price 94s. (No. 1324).

### Statics and Hydrostatics.

C. G. Lambe.

English Universities Press Ltd. 1965. Price 7s. 6d. (No. 1325).

### Pulse Generators in Industrial Electronics.

S. Littwin.

Illife Books Ltd. 1965. Price 16s. (No. 1326).

### Nonlinear and Parametric Phenomena in Radio Engineering.

A. A. Kharkevich.

Illife Books Ltd. 1965. Price 35s. (No. 1327).

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